PLOWSHARE

TID-3522
(8th REV.) (Suppl.1)

A SELECTED, ANNOTATED BIBLIOGRAPHY OF THE CIVIL, INDUSTRIAL, AND SCIENTIFIC USES FOR NUCLEAR EXPLOSIVES

United States Atomic Energy Commission
Division of Technical Information

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TID-3522(8th Rev.) (Suppl. 1)
NUCLEAR EXPLOSIONS—PEACEFUL APPLICATIONS (TID-4500)

PLOWSHARE

A SELECTED, ANNOTATED BIBLIOGRAPHY OF THE CIVIL, INDUSTRIAL, AND SCIENTIFIC USES FOR NUCLEAR EXPLOSIVES

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April 1969

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ABSTRACT

This supplement to TID-3522(8th Rev.) contains 265 annotated references to reports and published literature on the USAEC's Plowshare Program. The references are arranged by subject category. Report Number and Availability, Film and Tape, Author, and Experiment Indexes are included.

INTRODUCTION

The PLOWSHARE Program was formally established by the United States Atomic Energy Commission in 1957. This program, to study the feasibility of using nuclear explosives for peaceful purposes, has many potential applications in such areas as excavation of harbors, canals, and mountain passes, production of transplutonium isotopes, neutron physics research, gas and oil recovery and storage, waste disposal, mining, and water management. Laboratory and field experiments are currently under way to develop basic technology and to evaluate proposed applications.

This bibliography is Supplement 1 to TID-3522, 8th Revision, and contains previously omitted items plus material published between May 1, 1966 and April 30, 1968. Although every effort has been made to include all pertinent reports and published literature through April 30, 1968, omissions unfortunately are unavoidable and any suggested additions would be welcomed.

The assistance of Mrs. Marie Hawkesworth, Division of Peaceful Nuclear Explosives, and Mrs. Alice Twitty, Division of Technical Information Extension, in preparing this bibliography is gratefully appreciated.

REFERENCES

I. GENERAL

A. APPLICATIONS

Published Literature

1 ANNUAL REPORT TO CONGRESS OF THE ATOMIC ENERGY COMMISSION FOR 1967. Washington, D. C., Atomic Energy Commission, 1968. 409p. GPO.

Highlights of the United States Atomic Energy Program in 1967 are presented. Separate chapters are included for activities in the development of: source and special nuclear materials, safeguards and materials management, the nuclear defense effort, naval propulsion reactors, reactor development and technology, licensing and regulation, operational safety, nuclear rocket propulsion, specialized nuclear power units, isotopic radiation applications, the Plowshare Program, international cooperation, information services, nuclear education and training, basic research, industrial participation, and administration and management.

2 COMMERCIAL APPLICATIONS OF NUCLEAR EXPLOSIVES. Coffer, H. F.; Aronson, H. H. (CER Geonuclear Corp., Las Vegas, Nev.). 18p. (CONF-660606-49). Gmelin, AED-CONF-66-203-100.

From American Nuclear Society Meeting, Denver.

Potential uses of nuclear explosives with emphasis on gas well stimulation are discussed. The uses of nuclear explosives to recover oil from oil shale, create underground storage capacity for gas and waste disposal, break up large ore bodies for underground leaching, and for evacuation of canals and harbors are summarized. Problems which must be met before nuclear explosions become common in commercial applications are discussed. Such problems consist of determining the potential damage from shock waves and the type of radiation problem, if any, which must be overcome. In addition, the most economical methods of fielding and firing the devices must be worked out to maximize the profit potential from the use of this tremendous power source.

3 ENGINEERING FEASIBILITY OF NUCLEAR BLASTING. Hartman, Howard L. Argonne Nat. Lab. Rev., 3: 33-40 (Apr. 1966).

An evaluation of the peaceful potential of nuclear explosives for industrial and public-works purposes is presented. The economic, safety, and technologic feasibility of such a program is discussed.

4 INDUSTRIAL AND SCIENTIFIC APPLICATIONS FOR NUCLEAR EXPLOSIVES. Gerber, Carl R. J. Brit. Nucl. Energy Soc., 6: 24-47(Jan. 1967).

The effects of nuclear explosions are reviewed, and the course of cavity chimney formation in an underground explosion is described; formulae are given for cavity radius and chimney height estimation. Studies of large-scale excavation are continuing and the possibility of a sea-level canal between the Atlantic and Pacific Oceans is currently under examination. Other applications discussed include the stimulation of oil and natural gas reservoirs, the liberation of petroleum from oil shale, the storage of crude oil and natural gas, applications in the mining industry, and the development and management of water resources. Safety is discussed from the points of view of seismic waves and release of radioactivity. Projected charges of $350,000 to $600,000 for 10 kt to 2 Mt for thermonuclear explosives are published for use by industry in feasibility studies. The scientific research application is considered for the strong shock waves, hot plasmas, x rays, gamma rays, neutrons and electrons produced in nuclear explosions. The uses of the effects in neutron physics, heavy element, and seismic studies are discussed.

5 MAJOR ACTIVITIES IN THE ATOMIC ENERGY PROGRAMS, JANUARY–DECEMBER 1966. Washington, D. C., Atomic Energy Commission, 1967. 510p. $1.75. GPO.

The major activities in the atomic energy programs for January through December 1966, of the U.S.A.E.C. are described. Topics included are licensing and regulating the atom, reactor and other nuclear facility licensing, regulation of radioactive materials, source and special nuclear materials, nuclear defense effort, naval propulsion reactors, reactor development and technology, space nuclear systems, isotopic heat and power applications, isotopic radiation development, Plowshare program, international cooperation activities, research facilities and projects, nuclear education and training, informational activities, operational safety, industrial participation aspects, and administrative and management matters.

6 NUCLEAR EXPLOSIVES IN CIVIL ENGINEERING. Comit. Naz. Energ. Nucl. Notiz., 12: No. 6, 54-60(June 1966). (In Italian).

An extensive discussion of the past, current, and planned activities in the United States concerning the peaceful uses of nuclear explosives, particularly for industrial purposes, is given.

7 PLOWSHARE: PEACEFUL USES OF NUCLEAR EXPLOSIVES. Nucl. News, 11: No. 3, 23-44(Mar. 1968).

The development of technology for the peaceful use of nuclear explosives is described. The uses of nuclear explosives in large-scale earth moving projects such as digging sea-level canals, stripping rock layers from deep mineral deposits, cutting highways and railway passes through mountains, and the creation of harbors and lakes are described. The use of contained underground explosions to facilitate mining of ores and recovery of oil, to stimulate the flow of natural gas, or to produce underground reservoirs and permeable zones for storage or disposal of radioactive waste is discussed. The development of "clean" nuclear devices is also briefly discussed.

8 PLOWSHARE IN UNIVERSITY PROGRAMS. Talley, Wilson K. 5p. (CONF-660606-48). Gmelin, AED-CONF-66-203-96.

From American Nuclear Society Meeting, Denver.

University courses and research in the constructive uses of nuclear explosions are summarized. Prospects for more courses involving more disciplines, such as physics, chemistry, geology, mathematics, meteorology and engineering are evaluated.

9 TEN YEARS OF PLOWSHARE. Jackson, Melvin W. (Holmes and Narver, Inc., Los Angeles). Contract AT(29-2)-20. Civil Eng. (N. Y.), 37: 34-8(Dec. 1967). (HN-20-1023).

The development of engineering uses for nuclear explosives in the past ten years is summarized. For commercial utilization, nuclear explosives must become competitive with rapidly changing technology in earthmoving and mining. The Plowshare project has been instrumental in developing peaceful uses of nuclear energy since its formation in 1957.

10 UNCONVENTIONAL POWER PRODUCTION ON A GIGANTIC SCALE. Mawardi, O. K. (Case Inst. of Tech., Cleveland). New York, Inst. of Electrical and Electronics Engineers, 1966, Preprint No. 31 CP 66-46, 15p., $1.00. (CONF-660108-4).

From IEEE Winter Power Meeting, New York.

Two schemes to demonstrate the possibility of exploiting the natural potential energy of the earth to extract power in large quantities without depleting fossil fuel resources are suggested to meet the increasing power needs of the next 15 years. One scheme proposes to explode fusion-type nuclear explosions in cavities in the earth in high thermal gradient regions to reduce heat losses by convection through the earth. The second scheme is a hydromagnetic conversion scheme or ocean current generator to use the energy of the mass transport of sea water in the swift ocean currents. Calculations of the amount of energy probably available from each scheme are presented.

11 THE USE OF NUCLEAR EXPLOSIVES IN ENGINEERING AND INDUSTRY. Johnson, G. W.; Higgins, G. H. (Univ. of California, Berkeley). J. Brit. Nucl. Energy Soc., 5: 60-71(Jan. 1966). (UCRL-14314).

A single hydrogen bomb with a total volume no greater than a bulldozer can move more dirt in seconds than the bulldozer can in months and at a $1/100$th the cost. To harness this explosive power for peaceful applications has been the aim of the Plowshare Program, established in 1957 under the directorship of G. W. Johnson. Because of early interest by the Panama Canal Company in the possible excavation of a sea level canal, the development program has been concerned with reducing radioactivity in fallout to a minimum, and developing cratering technology. Concurrently, numerous studies of underground mining applications were carried out and the general understanding of underground nuclear explosions was expanded. The present state of knowledge of nuclear explosions in various environments for both deeply buried, contained explosions, and for less deeply emplaced charges which result in craters is described.

Reports

12 (AEC-tr-6777) UNDERGROUND NUCLEAR EXPLOSIONS. PROBLEMS OF INDUSTRIAL NUCLEAR EXPLOSIONS. Nifontov, B. I.; Protopopov, D. D.; Sitnikov, I. E.; Kulikov, A. V. Translation of Podzemnye Yadernye Vzryvy. Problemy Promyshlennykh Yadernykh Vzryvov, Atomizdat, Moscow, 1965. 189p. (PNE-3004). Dep. mn.

Industrial uses of underground nuclear explosions are reviewed. These uses include the construction of large civil engineering structures, mineral mining, extraction of petroleum from oil shales, generation of electrical power, and other scientific and technological uses. Also discussed are the optimum conditions under which underground nuclear explosives are detonated, internal and external effects, and seismic and air compression effects. The Gnome and Sedan experiments are also reviewed.

13 (CEA-Bib-63) APPLICATIONS SCIENTIFIQUES DES EXPLOSIONS NUCLEAIRES. 1 ERE PARTIE. EXCAVATIONS (CRATERING). (Scientific Applications of Nuclear Explosions. Part 1. Cratering). Berton, Micheline (Commissariat a l'Energie Atomique, Saclay (France). Centre d'Etudes Nucleaires). Oct. 1965. 90p. Dep. mn.

This bibliography is made up of 283 references to documents, almost all American, on the subject of the formation of craters by nuclear explosives. They are presented in three groups: reports; review articles; and symposia, films, and books. The documents are grouped together according to the important American programs for using the explosions for civil engineering work: extensive excavations, building of ports, canals, dams, drilling of mines. The research concerns the detection of explosions, and the seismological phenomena produced by the explosions have been deliberately omitted. The numerous PLOWSHARE projects have been gathered together up to the last reports cited in May 1965 by the Saclay Central Library. A subject index is included.

14 (CEA-Bib-66) APPLICATIONS SCIENTIFIQUES DES EXPLOSIONS NUCLEAIRES. 2 EME PARTIE. GEOLOGIE, SEISMOLOGIE ETUDE DES SOLS, FRACTURE DES ROCHES. (Scientific Applications of Nuclear Explosions. Part 2. Geology: Seismology, Soil Studies, Rock Fissuring). Berton, Micheline (Commissariat a l'Energie Atomique, Saclay (France). Centre d'Etudes Nucleaires). Dec. 1965. 158p. Dep. mn.

Seven hundred (700) references are given to journals and reports published from 1960–1965. The references are classified into two main groups: first, seismology, then studies concerning the behavior of soils, grounds, and subterranean waters when rocks are cracked during nuclear explosions. An author index is included.

15 (NP-15867) ESPLOSIONI NUCLEARI SOTTERRANEE. (Bibliography on Underground Nuclear Explosions). (Comitato Nazionale per l'Energia Nucleare, Casaccia (Italy). Centro di Studi Nucleari). [1963]. 52p. Dep. mn.

References (307) are given to reports and journals published from 1950 through 1962. Report number indexes are included.

16 (NP-16359) FOURTEENTH ANNUAL REPORT FOR THE YEAR ENDED 30TH JUNE, 1966. (Australian Atomic Energy Commission). 104p. Dep. mn.

Developments in research carried out by the AAEC on nuclear power, peaceful uses of nuclear explosives, nuclear desalination, raw materials, and radioisotopes are reported.

17 (PNE-3005) GENERAL REPORT ON THE ECONOMICS OF THE PEACEFUL USES OF UNDERGROUND NUCLEAR EXPLOSIONS. Morgenstern, Oskar; Heiss, Klaus-Peter (Mathematica, Princeton, N. J.). Aug. 31, 1967. Contract AT(04-3)-691. 218p. Dep.

An evaluation of the economics of the Plowshare program is presented. The four major applications include the stimulation of gas and oil reserves, production of shale oil, mining, and cratering. An analysis is made of the costs of nuclear explosives such as implacement costs, cost of the devices, safety, and an estimate of the potential benefits to the economy. Other uses of nuclear excavations, such as the development of underground storage reservoirs for fuels, water, and wastes, are considered. It is concluded that there exists substantial economic benefits in each of the four principal fields of peaceful uses of nuclear explosives.

18 (PRNC-110) PUERTO RICO NUCLEAR CENTER PLOWSHARE WORKSHOP, JULY 1–AUGUST 15, 1967. Pedersen, Knud B. (ed.). (Puerto Rico Nuclear Center, Mayaguez). Contract AT(40-1)-1833. 137p. Dep.

A six week workshop was conducted at the Puerto Rico Nuclear Center, starting July 1, 1967, to provide a complete background for its scientific staff and the University of Puerto Rico faculty members on the scientific bases, phenomenology, engineering principles, and constructive uses of nuclear explosives. A graduate course in nuclear civil engineering will evolve from this background material. Tables are presented of reference literature, the lecture topics, and the titles of 52 lectures. The appendixes present some lectures related to nuclear explosions and cover a variety of subjects including seismic waves and elastic theory, procedures for developing construction projects, and applications of nuclear explosions for canal and harbor excavation, gas production and stimulation, oil recovery, mining, salt water distillation, and commercial radioisotope production.

19 (TID-3522(8th Rev.)) PLOWSHARE: A SELECTED, ANNOTATED BIBLIOGRAPHY OF THE CIVIL, INDUSTRIAL, AND SCIENTIFIC USES FOR NUCLEAR EXPLOSIVES. Gerber, Carl R. (Division of Peaceful Nuclear Explosives (AEC), Washington, D. C.); Voress, Hugh E. (comps.) (Division of Technical Information Extension (AEC); Oak Ridge, Tenn.). May 1966. 108p. Dep. mn.

This bibliography presents annotated references arranged by subject. A guide to where the reports may be obtained and their cost, a separate listing of the films available, and an index of where information on specific projects may be found follow the annotated references. Author and report number indexes are also included.

20 (TID-23748) NUCLEAR CIVIL ENGINEERING OUTLINE SYLLABUS FOR CE 277 GIVEN WINTER QUARTER, 1966. Technical Report No. 70. Kruger, Paul (Stanford Univ., Calif. Dept. of Civil Engineering). Sept. 1966. Contract AT(04-3)-326. 330p. Dep.

A compilation of lecture notes for a course in Nuclear Civil Engineering at Stanford University based on progress achieved by the Plowshare Program in harnessing the power of nuclear explosives for peaceful purposes is presented. The lectures are grouped as follows: science and technology of contained and cratering nuclear explosives; experiences of the Plowshare Program; hazards from radioactivity, air blast, seismic shock, and groundwater contamination; and the potential applications in science, construction, water resource management, and geologic industries such as petroleum, gas, and mining.

21 (UCRL-Trans-10152) THE THERMONUCLEAR "BULLDOZER" WILL SOON BE IN USE. Use of Nuclear Bombs to Carry Out Large Engineering Projects Previously Thought Economically Impossible. Roy, Jean-Rene. Translated by Robert Addis for Univ. of California, Lawrence Radiation Lab., Livermore, from Jeune Sci., 5: 36-41(1966). 24p. Dep.

The use of nuclear explosions in excavations is discussed. The USAEC's Plowshare Program for the utilization of nuclear explo-

sives for peaceful purposes is described. Hazards of radiation and shock waves are also described. The prospects for constructing the new Panama Canal and the two-mile long Bristol Mountain trench with nuclear explosives are discussed. A brief summary of the uses of nuclear explosions for oil production, release of natural gas, isotope production and physics research is given.

B. PHENOMENOLOGY AND SAFETY

Published Literature

22 A SURVEY OF COMPLAINTS OF SEISMIC-RELATED DAMAGE TO SURFACE STRUCTURES FOLLOWING THE SALMON UNDERGROUND NUCLEAR DETONATION. Power, Dean V. (Univ. of California, Livermore). Bull. Seismol. Soc. Amer., 56: 1413-28(Dec. 1966). (UCRL-14110(Rev.1)).

Following the 5-Kt Salmon underground nuclear experiment in Mississippi, many unexpected complaints of damage were received from residents living 15 to 40 Km distant. The claimed damage was mostly cracks in plaster, stucco, and masonry. Ground motion at these ranges was within the predicted safe limits, with peak surface-particle velocities roughly an order of magnitude below the 5 to 10 cm/sec level previously accepted as the threshold for damage. It is shown that a 5 cm/sec damage threshold does not apply to this area, and revised damage criteria need to be formulated that take into consideration geology, frequency spectrum, and other factors in addition to surface particle velocity. The claimed damage was similar to that normally found in Mississippi homes and attributed to poor foundation soils. The triggering by the Salmon detonation of naturally occurring settlement cracks is suspected, but the physics of the process is not yet fully understood.

23 AIR-BLAST SUPPRESSION AS A FUNCTION OF EXPLOSIVE-CHARGE BURIAL DEPTH. Vortman, L. J. (Sandia Corp., Albuquerque, N. Mex.). J. Acoust. Soc. Amer., 40: 229-39 (July 1966). (SC-R-66-898).

The blast wave from buried explosions consists primarily of a pulse induced by the ground shock followed by another pulse when the explosive gases are vented to the atmosphere. The latter pulse provides the dominant contribution for the shallower burial depths. Air-blast measurements made along the ground surface for 46 chemical explosive and 7 nuclear explosive detonations have shown the peak overpressure of the ground-shock-induced pulse to be about the same for chemical and nuclear explosions in basalt rock as for chemical explosions in alluvial soil. The ground-shock-induced pulse has not been observed for nuclear explosions in soil. The peak overpressure from venting gases is about equal for chemical explosives in basalt rock and alluvial soil. Peak overpressures are higher for nuclear explosions in soil, in part because the cavity pressures at the time of venting are higher; peak overpressures are lower for nuclear explosions in rock, presumably because less gas is formed and because the pulse from venting gas coincides with the negative phase following the ground-shock-induced pulse, thus reducing overpressure amplitude. Measurements have been made over a sufficiently large range of charge burial depths that a pattern of air-blast suppression with charge burial can be presented.

24 AMPLITUDE VARIABILITY OF EXPLOSION WAVES AT LONG RANGES. Reed, Jack W. (Sandia Lab., Albuquerque, N. Mex.). J. Acoust. Soc. Amer., 39: 980-1(May 1966). (SC-R-66-886).

Three airburst high-explosive calibration shots were fired at H − 2, H + 4, and H + 7 min to determine the airblast wave amplitude transmitted from an underground nuclear test. Microbarograms, made at long range from the three 10^8-g high explosives, were compared to show atmospheric propagation variability. Records made at 40−250-km ranges gave amplitude repeatability with a logarithmic-normal standard deviation of 0.49.

25 ATMOSPHERIC REFRACTION AND FOCUS OF BLAST WAVES. Viecelli, James (Univ. of California, Livermore). J. Geophys. Res., 72: 2469-83(May 15, 1967).

An integral solution to the wave equation in an inhomogeneous half-space is used to derive the time-dependent pressure variation in the neighborhood of a first focus. Theoretically calculated signals are compared with barograph records. Conclusions are: (1) The curve of maximum peak-to-peak pressure versus distance is bell shaped; the dome of the bell is located on the far side of the caustic. (2) Width of the bell is proportional to the $^2/_3$ power of the energy released to the atmosphere. (3) Height of the dome is proportional to the $^5/_{18}$ power of the energy release. (4) The signal wave shape is quite sensitive to position near the caustic: on the near side the signal consists of a single long smooth wave; at the caustic the wave steepens into a spike followed by a dip; on the far side the signal divides into two separate portions, a relatively smooth wave followed by a period of silence followed by a wave containing a spike. (5) Close correlation between theoretical and observed signals is unlikely for a single event at a single recording station. (6) The theoretical focus is narrower and more intense than that experimentally observed.

26 CONSTRUCTIVE USES OF NUCLEAR EXPLOSIVES. Teller, Edward; Talley, Wilson K.; Higgins, Gary H.; Johnson, Gerald W. New York, McGraw-Hill Book Company, 1968. 332p. $12.75.

The results of research on the constructive uses of nuclear explosives are summarized. Information is included on the effects of nuclear explosions, aspects of energy transfer, radioactivity, Plowshare tests, earth moving and other industrial uses, and scientific applications.

27 DYNAMICS OF SPALLING OF THE EARTH'S SURFACE CAUSED BY UNDERGROUND EXPLOSIONS. Chilton, Frank; Eisler, J. D.; Heubach, H. G. J. Geophys. Res., 71: 5911-19 (Dec. 15, 1966).

The dynamics of spalling of the near-surface layers caused by contained underground explosions was investigated theoretically. Spalling of these layers is a consequence of propagation of compressive and tensile stresses in the subsurface. Tensile stresses are produced by the reflection of compression stresses from the free surface.

28 ELECTRICAL TRANSIENTS OBSERVED DURING UNDERGROUND NUCLEAR EXPLOSIONS. Zablocki, C. J. (Geological Survey, Denver). J. Geophys. Res., 71: 3523-42(July 15, 1966).

Electric transients were recorded from eleven underground nuclear explosions at the Nevada Test Site and from one near Carlsbad, New Mexico. The electric field components are only a few microvolts per meter at distances less than 10 km from the shot point, and they generally decay approximately as the inverse cube of distance. Magnitudes are proportional to about the 0.4 power of yield. Two source mechanisms are considered: the formation of an elementary magnetic dipole by the conductive plasma expanding in the earth's magnetic field and the formation of an elementary electric dipole by radial asymmetry in the generation and absorption of β rays. The data accordingly were interpreted in terms of equivalent buried dipole sources.

29 FREE-FIELD MOTION NEAR A NUCLEAR EXPLOSION IN SALT: PROJECT SALMON. Rogers, Leo A. (Univ. of California, Livermore). J. Geophys. Res., 71: 3415-26(July 15, 1966).

Calculations (SOC computer code) of shock pressure, position, velocity, and material displacement were made for the Salmon detonation (design yield of 5 kt) based both on results from the Gnome event (3.1 kt in salt) and physical properties measurements of the material in the shot region. Comparison of the calculations with experimental data gives agreement for peak pressure and peak velocity within 20 to 50% over the range calculated (1 to 600 meters). Calculations and observations agreed to within 1 to 10% for shock wave arrival times, to 25% for displacement of the salt at 300 meters, and to within 10 to 50% for ground surface motion directly above the shot. The calculations based on physical properties measurements from the shot region generally gave better agreement with the data than those extrapolated from the Gnome event. The central cavity apparently grew to a radius of 24 m during the initial dynamic stage and then contracted back to a radius of 17 meters after the shot.

30 HIGH-RESOLUTION SEISMIC UPHOLE SURVEYS AT THE LAWRENCE RADIATION LABORATORY. Carlson, R. C. (Lawrence Radiation Lab., Mercury, Nev.); Stearns, R. T.; Berens, H. B.; Hearst, J. R. Geophysics, 33: 78-87(Feb. 1968).

Use of the uphole survey method to achieve high resolution velocity measurements for underground nuclear explosion seismic studies is reported. Methods were developed to measure the source and arrival times of an explosion-induced acoustic wave to within 0.1 msec. These methods were used to measure acoustic velocity over distances of 10 to 150 m with high accuracy. The methods are usable in dry holes, and were used in rhyolite, tuff, dolomite, alluvium, and shale to measure velocities between 700 and 5000 m/sec. Statistical errors on the order of ±2 to 5% were achieved in most cases. It is concluded that the accuracy of such measurements is

limited only by the frequency transmission of the medium, not by the instrumentation. The instrumentation used is described.

31 MULTIPLE SUBSURFACE SPALLING BY UNDERGROUND NUCLEAR EXPLOSIONS. Eisler, J. D. (Stanford Research Inst., Menlo Park, Calif.); Chilton, F.; Sauer, F. M. Contract W-7405-eng-48. J. Geophys. Res., 71: 3923-7(Aug. 15, 1966). (UCRL-13195(Rev.1)).

Multiple spalling of subsurface layers in the earth accompanies the detonation of contained underground nuclear shots. Interpretation of available data for shots detonated in tuff, halite, and alluvium points to the existence of ascending and descending waves which produce spall gaps in the subsurface. The records of particle acceleration at depth indicate an upward-traveling sequence of closures of these gaps. The pattern of spallation is similar for the tuff and halite shots. For an alluvium shot, spallation appears to be largely the consequence of slumping of the cavity rather than of tensile stress waves reflected from the free surface.

32 PARTICLE MOTION NEAR A NUCLEAR DETONATION IN HALITE. Weart, Wendell D. (Sandia Corp., Albuquerque, N. Mex.). Bull. Seismol. Soc. Amer., 52: 981-1005(Dec. 1962).

To determine the characteristics of earth motion parameters resulting from a nuclear explosion, measurements of acceleration, particle velocity, particle displacement, stress, and strain were made along a horizontal radius in the halite stratum where a nuclear device (Project Gnome) of nominal 5-Kt yield was detonated 360 m below the surface of the ground. The measurements extended from the zone of intense cracking and plastic flow (60 m) out into the elastic zone (480 m), accelerations being measured along a vertical radius. Travel time data from the horizontal radius revealed 3 distinct arrivals. First arrivals were propagated through the polyhalite layer with a velocity of 4.839 km/sec. This was followed by the direct elastic wave arrival in the salt horizon (4.318 km/sec) and the plastic wave which decreased in velocity as the stress level diminished. Vertically, the velocity varied from 5.1 km/sec at about 60 m above the shot to 0.785 km/sec a few meters below the surface. Peak accelerations in the salt were best fitted by the relations $A = 890\ R^{-5.3}$ from 60 to 122 m and $A = 560\ R^{-2.7}$ from 122 to 480 m. (R in hundreds of meters and A in units of gravity.) Peak particle velocity in the salt is given by $U = 13\ R^{-3.56}$ from 60 to 100 m and $U = 13\ R^{-1.36}$ from 100 to 480 m. Motion of the ground above the shot revealed that spalling occurred at several horizons. The deepest spall separation was below 92 m. These effects were most pronounced at the surface where the initial acceleration, velocity and displacement peak values were A = 25 g, U = 5.6 m/sec, and D = 168 cm. Residual upward displacement at surface zero at +5 min was 79 cm.

33 POST-EXPLOSION ENVIRONMENT RESULTING FROM THE SALMON EVENT. Rawson, D.; Randolph, P.; Boardman, C.; Wheeler, V. (Univ. of California, Livermore). J. Geophys. Res., 71: 3507-21(July 15, 1966). (UCRL-14280(Rev.1)).

The Salmon event was a 5.3 ± 0.5 kt nuclear detonation at a depth of 827.8 m in the Tatum salt dome in Mississippi. The explosion created a nearly spherical cavity of radius 17.4 ± 0.6 m and vaporized and melted approximately 5.4×10^6 kg of rock which formed a puddle of recrystallized salt. At the time of penetration the cavity was under a partial vacuum with a pressure of less than 313 mb, and the temperature of its gases was about 205°C. Most of the explosion energy was in the form of heat distributed within 45 m of the shot point. Radioactive melt injected into cracks was observed as far as 37 m from the shot point, and radioactivity increased above background as far as 64 m. The wall rock was highly microfractured and contained some macrofractures. The most broken portion of the rock surrounding the cavity was observed in the region 39 to 50 m below shot point. The puddle at the base of the cavity was highly fractionated, with a high concentration of refractory radioactive species in the bottom few centimeters. Separation of ^{131}Xe in the cavity gas from the parent ^{131}I found in the puddle indicates that the puddle took 24 to 32 days to solidify. It is concluded that the resulting cavity is stable and could be used for an experimental investigation of full or partial decoupling; however, the material surrounding the cavity is less competent than it was before the shot, and the present strength and stress distribution of the rock are not known.

34 PRELIMINARY STUDIES OF THE PERSISTENCE OF TRITIUM AND ^{14}C IN THE PACIFIC PROVING GROUND. Koranda, John J. (Univ. of California, Livermore). Health Phys., 11: 1445-57(Dec. 1965). (UCRL-12302-T).

The results of a preliminary survey of detonation environments in the Pacific Proving Grounds indicate that residual tritium and ^{14}C are present in relatively high concentrations in soil materials of the detonation sites at times up to 12 years after the event. Exchange of soil-bound tritium with the available soil water takes place at a slow but significant rate and tritium is detectable in plants growing in the detonation environments. Carbon-14 is also elevated in the terrestrial plants. The basis for the elevated ^{14}C is not implicit in these preliminary data. Tritium and ^{14}C are also present in elevated concentrations in marine organisms. However, due to the high rate of exchange of the lagoon waters with the open sea, these elevated concentrations are highly localized in the vicinity of the detonation site (Mike Crater).

35 SEISMIC-INDUCED ARCHITECTURAL DAMAGE TO MASONRY STRUCTURES AT MERCURY, NEVADA. Wall, John F. Jr. (Univ. of California, Livermore). Bull. Seismol. Soc. Amer., 57: 991-1007(Oct. 1967).

An investigation was made of selected representative buildings in Mercury, Nevada, close to many nuclear detonations within the Nevada Test Site, to determine: the validity of peak-particle velocity as a damage criteria, the peak-particle velocity which causes minor architectural damage to selected masonry structures, and the natural cracking rate for this type of structure in Nevada. Building exteriors of 41 Mercury concrete block and 2 lift-slab structures were inspected before and after detonations which gave peak-particle velocities in the range of 0.1 to 0.5 cm/sec. Only one building was older than 3 yr, and all were at distances of 33 to 78 km from the Nevada Test Site. Findings included evidence that peak-particle velocities of 0.1 to 0.3 cm/sec caused, on the average, 24 cracks in the 43 buildings, as compared to about 2.5 cracks during a similar time span of no nuclear activity. Cracks of these low levels of motion were not more severe than those occurring naturally. The Mercury experience indicated that, at that particular location, cracks occur naturally in concrete block structures at a standard or seasonal rate, and that cracking caused by ground motion from nuclear detonations would have occurred naturally in a matter of time.

36 SOME NOTES ON FORECASTING OF WINDS ALOFT BY STATISTICAL METHODS. Reed, Jack W. (Sandia Corp., Albuquerque, N. Mex.). J. Appl. Meteorol., 6: 360-72(Apr. 1967).

Winds aloft statistics from Eniwetok were used to derive a linear regression forecast technique that verified satisfactorily in later application. Other studies showed that these principles were applicable throughout the tropical Pacific Ocean area. Time-lag correlation coefficients were found to decay exponentially with increased time except in the first 6 hr, when decay was more rapid. This has been interpreted as the effect of measurement error and small-scale turbulence. A method was derived for removal of these random errors and, on application, time-lag correlation coefficients for each altitude were then found to decay at constant exponential rates, to at least 48 hr. This indicates that no improvement in regression forecasting can be achieved by use of multiple-term regressions from sequential data. Also, regression forecast verifications can be significantly improved by (1) removing the instrument error by hardware techniques and (2) smoothing out small-scale turbulence by multiple observation. This general technique is also shown to be useful in forecasting for other latitudes but comparison with other forecast methods for middle and high latitudes has not been made.

37 SURFACE DISPLACEMENTS DUE TO AN UNDERGROUND EXPLOSION. Bycroft, G. N. (Stanford Research Inst., Menlo Park, Calif.). Bull. Seismol. Soc. Amer., 56: 877-88 (Aug. 1966).

The problem of estimating surface displacements of the earth due to underground explosions, particularly in the case of detection of nuclear testing, is considered. The earth is not a linearly elastic half-space and close to the source of the explosion many phenomena take place, but outside some particular spherical surface centered at the origin of the explosion an elastic description of the wave propagation provides a first approximation. The simple solution to the problem of the surface displacements on an elastic half-space which is presented is based on derivation of the transient case for a point source from the steady state point source and then proceeding to the case of a finite spherical cavity by means of a retarded potential. Theoretical values of maximum displacement compared favorably with measured values from the underground test shot Rainier, a nuclear explosion of Operation Plumbbob. The analysis which is shown gives explicit solutions to the surface displacements when a Heaviside jump in velocity is imposed on a sphere of zero radius. Simple convolution formulas allow these results to be extended to the case of a velocity of arbitrary shape imposed on a spherical cavity of finite radius up

to the time when waves are reflected back from the spherical cavity to any point on the surface in question. Computed values of the maximum vertical displacements measured during an underground nuclear test compared favorably with the theoretical values.

38 TIME HISTORY OF THE CAVITY PRESSURE AND TEMPERATURE FOLLOWING A NUCLEAR DETONATION IN ALLUVIUM. Olsen, Clifford W. (Univ. of California, Livermore). J. Geophys. Res., 72: 5037-41(Oct. 15, 1967).

The cavity pressure following a nuclear detonation in alluvium at the Nevada Test Site has been measured from about 45 sec until subsidence at 10.2 min. The pressure was found to follow the expression P (bars) = 36.7 $e^{-0.36t}$ + 7.8 for about 7 min. Such a pressure history corresponds to simple cooling of a steam-filled cavity with a surface heat-transfer coefficient of 0.012 cal/cm^2 sec °K. Original pressure, after the completion of cavity growth, was apparently overburden pressure. The difference between measured and calculated pressure after about 7 min can be explained as the result of condensation of the steam. After condensation begins, the pressure is simply the vapor pressure of water. The observed pressure is used to calculate the apparent rate of condensation and the necessary heat-transfer rate. The surface heat-transfer coefficient after the onset of condensation is found to be about 1 cal/cm^2 sec °K, a value that implies spalling of the cavity surface.

39 TRACE ELEMENTS IN COMMON ROCK TYPES AND THEIR RELATIVE IMPORTANCE IN NEUTRON-INDUCED RADIOACTIVITY CALCULATIONS. Day, Walter C.; Paul, Roger A. (Univ. of California, Livermore). Health Phys., 14: 311-29(Apr. 1968).

The chemical composition of the rock surrounding an underground nuclear detonation must be known or assumed when calculations of the resulting neutron-induced radioactivity are attempted. A typical chemical analysis of rock samples does not include certain trace elements which have high neutron-capture cross sections. A literature search was undertaken to determine the average and range of content of these trace elements in common rock types, to permit an evaluation of their relative importance in neutron-induced radioactivity calculations. The elements considered in the study were Dy, Gd, Eu, Sm, Nd, Cd, Ag, Co, Cr, V, Sc, Cl, S, B, and Li. Data are reported giving the contents of these elements in ten igneous rock types and three sedimentary rock types. The five elements Gd, Eu, Sm, B, and Cl were found to occur in most rock types in quantities which would significantly affect neutron-induced radioactivity calculations. Calculations of induced radioactivity were performed for granite using maximum, average, and minimum trace element values obtained from the literature search. Calculations were also performed using average trace element values for four other igneous rocks and three sedimentary rocks. It is concluded that, in general, use of the average values for trace elements presented in this paper is adequate for assessing the quantities of radionuclides induced external to the device for use in feasibility studies for large scale excavation projects and other underground nuclear detonations when detailed chemical analyses of emplacement media are not available.

Films

40 SAFETY IN THE PLOWSHARE PROGRAM (1966), (USAEC's Nevada Operations Office, producer) For sale by Consolidated Film Industries, 959 Seward St., Hollywood, Calif. 90038, at $67.83 per print, including shipping case, F.O.B. Hollywood. Available for loan (free) from USAEC headquarters and field libraries. Cleared for television.

This motion picture, which is a companion piece to the USAEC film "Plowshare" documents the means taken to ensure the safety of the public during experiments or projects in the U. S. program to develop peaceful uses of nuclear explosives. The film relates the effects of underground explosions to the varying purposes for the explosions and to public safety. (This is a correction to Item No. 87 in TID-3522, 8th Rev.).

Reports

41 (CONF-671029-1) PUBLIC HEALTH ASPECTS OF THE CIVILIAN APPLICATIONS OF NUCLEAR EXPLOSIVES (PLOWSHARE) PROGRAM. Barth, D. S. (Public Health Service, Las Vegas, Nev. Southwestern Radiological Health Lab.). Sept. 1967. Contract SF-54-373. 12p. Dep.

From International Health Symposium, Miami Beach, Fla.

The work being carried on within the Plowshare Program is presented. This includes an introduction to studies in the categories of research and development, excavation experiments, scientific research experiments and underground engineering experiments. Particular attention is devoted to public health aspects of the excavation and the underground engineering applications. Potential hazards which may be associated with ground shock as well as those related to nuclear radiation are discussed in general terms. An inventory of some radionuclide activities expected to be released from nuclear cratering events of useful magnitude is presented.

42 (COO-1336-6) REACTION OF NATIVE ANIMALS LIVING IN THE VICINITY OF AN UNDERGROUND NUCLEAR DETONATION. Final Report. Jorgensen, Clive D. (Brigham Young Univ., Provo, Utah). Mar. 1, 1968. Contract AT(11-1)-1336. 115p. Dep.

NUCLEAR EXPLOSIONS, UNDERGROUND—effects on immediate and long-term movements of small mammals at Nevada Test Site

INSECTA—Eleodes sp., radiation effects on, at Nevada Test Site following underground nuclear explosion; Eusattus dubius, radiation effects on, at Nevada Test Site following underground nuclear explosion; Edrotes sp., radiation effects on, at Nevada Test Site following underground nuclear explosion; Trogloderus costatus, radiation effects on, at Nevada Test Site following underground nuclear explosion; Pelecyphorus sp., radiation effects on, at Nevada Test Site following underground nuclear explosion; Stenopelmatus fuscus, radiation effects on, at Nevada Test Site following underground nuclear explosion

ARACHNIDA—Globipes spinulatus, radiation effects on, at Nevada Test Site following underground nuclear explosion; Anuroctonus phaeodactylus, radiation effects on, at Nevada Test Site following underground nuclear explosion

ARACHNIDA—Vejovis sp., radiation effects on, at Nevada Test Site following underground nuclear explosion

43 (DP-1106) DISTRIBUTION OF RADIOACTIVE ELEMENTS IN THE DEBRIS OF THE SALMON NUCLEAR TEST. Karraker, D. G.; Perkins, W. C. (Du Pont de Nemours (E.I.) and Co., Aiken, S. C. Savannah River Lab.). July 1967. Contract AT(07-2)-1. 14p. Dep.

Analysis of the debris of Salmon, an underground nuclear test detonated near Hattiesburg, Mississippi, showed that most of the isotopes formed during the explosion collected in a thin layer at the bottom of the original cavity. An explanation is offered for the vertical distribution of radioactive species in the debris.

44 (HNS-1229-43) GROUND-WATER MONITORING. Davis, Stanley N.; Lynch, Edward J. (Bradberry (Carroll E.) and Associates, Inc., Los Altos, Calif.). Dec. 18, 1963. Contract AT(29-2)-1229. 77p. Dep.

For Hazleton-Nuclear Science Corp., Palo Alto, Calif.

The underground detonation of a nuclear device introduces into the ground a potential source of contamination of nearby groundwater systems. This report presents a study of this problem from the aspect of detection and surveillance of such contamination. Monitoring of ground water for radionuclides is best accomplished by means of wells placed as close as possible to the source of contamination or to the predicted path of contaminant travel. Uncertainties in the spatial variations of porosity and permeability, along with inaccuracies in measuring hydraulic heads in some aquifers, make it difficult to predict the exact direction of movement of the contaminated water. Consequently, sufficient pumping of the wells is necessary to ensure that water from a large area is intercepted. Analytical expressions and nomograms have been developed to assist in estimating the necessary pumping rates, and the travel time and dilution of the contaminants en route to the monitor well. This information, combined with a detailed hydrologic study of an area of interest, will make possible the planning of an effective monitoring system. For greatest economy, the monitoring program should be planned in conjunction with other activities related to the preparation for a detonation.

45 (HNS-1229-54) A PROCEDURE FOR THE CALCULATION OF NEUTRON ACTIVATION OF AN INFINITE HOMOGENEOUS MEDIUM. C. L. Carnahan (Hazelton-Nuclear Science Corp., Palo Alto, Calif.). Sept. 15, 1964. Contract AT(29-2)-1229. 67p. Dep. (mn); $3.00(cy), 2(mn).

A method for the calculation of quantities of radionuclides induced in infinite, homogeneous media by neutrons from underground nuclear detonations is developed theoretically and a procedure for practical application of the theory is presented. Results of calculations are given for radionuclides, having half lives

greater than 0.5 year, induced by neutrons from fusion reactions and from fission reactions in media having the compositions of the average earth's crust, average carbonate rocks, and the Tatum salt dome, Hattiesburg, Mississippi. Separate calculations are made for fusion neutrons and for fission neutrons because of the great differences in the initial neutron energy distributions and in the total numbers of neutrons produced, per unit energy yield, by the two processes. The following types of reactions are treated: (n,γ), (n,p), (n,α), (n,2n), and (n,np). Secondary reactions and second-order reactions are not considered. Effects due to activation of device and emplacement materials are not considered, and effects due to special neutron-moderating and absorbing materials placed around the device are considered only very superficially. A sample calculation is included.

46 (NVO-22(Rev.1)) STUDY RELATED TO REPORTS OF DAMAGE FROM THE SALMON EVENT, PROJECT DRIBBLE. (Holmes and Narver, Inc., Las Vegas, Ney. On-Continent Test Div.). Mar. 1967. Contract AT(29-2)-20. 73p. Dep. mn.

On October 22, 1964, a coupled 5 kt nuclear device was detonated at a depth of approximately 2,700 feet in the Tatum Salt Dome, 23 miles from Hattiesburg, Mississippi. This detonation called the Salmon Event was one of the planned detonations of Project Dribble of the Vela Uniform Program. After the Salmon detonation, minor damage to structures was unexpectedly reported from areas for removed from surface zero. An investigation to determine whether the Salmon Event had caused damage to structures in areas beyond the predicted range of damage and to provide a supportable explanation for the cause of damage, if real damage had been ascertained, is reported. Prior to the Event predictions were made of the ground motions to be expected at different distances from surface zero. These ground motion predictions, when related to the generally accepted threshold of minor damage to plaster, indicated that the limit of minor damage to structures would be at 4.5 miles from surface zero. The criterion used for threshold of minor damage to plaster was based on earlier experiments with chemical explosions by other organizations. Guided by these pre-shot studies, existing structures with 4.5 miles of surface zero were surveyed and strengthened to prevent structural damage. It was concluded that newly formed minor damage to structures did occur beyond the predicted limit for damage of 4.5 miles and damaged structures were observed as far as 25 miles from surface zero, and in some cases the damage to these structures was caused by the Salmon Event. It was found that damage to structures exceeding 4.5 miles from ground zero was caused by the following: variations of transmission of seismic energy in certain directions was due to subsurface geology peculiar to the region, the peak value of ground motion as a criterion for predicting damage to the most susceptible structures was overestimated, and the current concept of a general threshold of damage expressed in terms of the maximum excursion of a ground motion parameter was found to be unsuitable for application in the Salmon Event.

47 (NVO-99-27) SPECTRAL RESPONSE TO GROUND DISPLACEMENT AT HATTIESBURG, RESULTING FROM NUCLEAR EVENT SALMON. Blume, John A. (Blume (John A.) and Associates Research Div., San Francisco, Calif.). Mar. 1968. Contract AT(26-1)-99. 31p. Dep.

Spectral response is developed from a record of ground displacement in Hattiesburg, Mississippi, resulting from the SALMON event, Project DRIBBLE, an underground nuclear explosion near Baxterville, Mississippi in October 1964. No acceleration records are available for Hattiesburg. It was found that peak response in the short period range could be reasonably estimated using as little as one second of selected motion from the entire record. A stochastic model of the key portion of the ground motion was constructed with a few sine pulses which essentially duplicate the short period peak response.

48 (NOV-99-30) DYNAMIC CHARACTERISTICS OF MULTISTORY BUILDINGS. Blume, John A. (Blume (John A.) and Associates Research Div., San Francisco, Calif.). Jan. 1968. Contract AT(26-1)-99. 44p. Dep.

To evaluate unit stresses or to estimate possible damage in multistory buildings from ground motion due to an earthquake or an underground nuclear explosion, it is essential to determine how much of the dynamic response at any level is due to various types of freedom. The effects of shear deformation between floors, joint rotation, overall flexure, and ground compliance are considered. Joint rotation and overall flexure are evaluated over a wide range of building characteristics with simply determined indices. A Period Synthesis concept and a Pseudo Stiffness Procedure are proposed to enable the determination of periods, mode shapes, and stiffnesses with consideration of joint rotation, overall flexure, and ground compliance while performing simple labor-saving analyses for assumed rigid-floor shear buildings. The first three modes of vibration are considered in elastic free vibration. The buildings and models are symmetric in plan without torsional coupling.

49 (NVO-1163-49(Rev.1)) A SUMMARY OF GROUND MOTION PREDICTION PROCEDURES AND EQUATIONS. Davis, Lawrence L. (Beers (Roland F.), Inc., Alexandria, Va.). Mar. 23, 1965. Contract AT(29-2)-1163. 50p. Dep.

In spite of the great number of instrumented underground events, large gaps exist in the empirical data. Even where data are available, the limitations in the frequency response of the instruments may have permitted a portion of the seismic energy to go undetected. Predictions can be made, with good empirical support, for events in Yucca Flat if the yields are less than Bilby and the event location is east of Yucca Fault. Tuff predictions have been reasonably well checked by data from a wide range of yields. For granite, the Shoal effects were predicted very well, but no check on yield scaling for events in granite is available. Detailed analysis of the Salmon data and comparison with the Gnome data may provide a better basis of predicting events in salt. However, the small range of yields is a serious drawback to the determination of empirical equations for general use. For other media, much more data are required before reliable empirical equations can be derived.

50 (NVO-1163-67) ANALOG COMPUTER STUDY OF BUILDING RESPONSE TO GROUND MOTION. Revised. Lynch, Robert D. (Environmental Research Corp., Alexandria, Va.). March 1, 1967. Contract AT(29-2)-1163. 16p. Dep.

From velocity measurements made on five high-rise structures, an empirical transfer function that relates top floor absolute velocity to base velocity is determined. Examples of simulated top floor motion derived from base motion are given for comparison with measured top floor motion.

51 (NVO-1163-78) THEORETICAL ANALYSIS OF THE THREE ZONE MODEL. Gorman, Richard L. (Environmental Research Corp., Alexandria, Va.). May 23, 1966. Contract AT(29-2)-1163. 106p. Dep.

The theoretical development of the three-zone model is treated. The model consists of an inner gaseous region, an intermediate zone which is assumed to have liquid properties, and an elastic region which is treated as an elastic solid. Apart from corrections due to the departure of cavity shape from sphericity, the model assumes spherical symmetry. The theory covered is based on linear elastic theory. Considerations have been made regarding variations in yield, effects of permanent compression, departure of cavity shape from sphericity, energy dissipation, etc. A linear theoretical description of the wave shape entering the elastic region from the cavity is made possible using only direct input parameters such as yield, elastic parameters of surrounding rock, etc. Nonlinear effects do occur in practice and existent shock-theoretical developments make use of these effects. The theory discussed in this report considers a wave form throughout the propagation medium and includes cavity resonances. Both shock theory and the theory using the three-zone model have their advantages and disadvantages. The theory developed here considers the processes occurring near the cavity in an underground nuclear explosion.

52 (NVO-1229-85) MOVEMENT OF GASEOUS RADIONUCLIDES THROUGH GEOLOGIC MEDIA. Smith, Mary E.; Carnahan, C. L. (Isotopes, Inc., Palo Alto, Calif.). Feb. 1968. Contract AT(29-2)-1229. 60p. Dep.

Underground nuclear explosions result in formation of certain radioactive gases which might be transported away from an explosion zone and create possible hazards to ground water supplies. Study of normal diffusion, under the sole influence of concentration gradients, indicates that this mechanism may not be adequate to account for observed ground-surface concentrations of radioactive gases at short times after deeply buried detonations, but might cause contamination of distant ground waters at much later times, of the order of tens of years after detonation. Further theoretical study of diffusional transport mechanisms and certain laboratory and field investigations would be useful in elucidating the mechanism or mechanisms by which such gas transport is effected.

53 (PNE-800F) STRONG-MOTION AND SURFACE ACCELERATIONS. Project HANDCAR. Mickey, W. V.; Lowrie, L. M. (Coast and Geodetic Survey, Washington, D. C.). Nov. 1965. Contract W-7405-eng-48. 75p. Dep. mn.

The 10 kt nuclear detonation, HANDCAR, in dolomite produced larger motions at seismic stations on deep alluvial deposits than those on hard rock with the larger magnifications observed on the horizontal radial component. Regression equations for maximum signal attenuation with distance indicated greater rate of attenuation for stations on hard rock as compared to stations on alluvium. First arrival velocities for stations beyond 2 km were near 5.26 km/sec with maximum displacements propagating at 1.09 and 1.66 km/sec on alluvium and hard rock, respectively, with 2.03 and 2.75 km/sec for maximum acceleration. The record length on the alluvial stations was about twice as long as those on hard rock. The direction of the resultant for horizontal first motion was normal to bedrock–alluvium contacts. Spectral analysis indicated lower frequencies for alluvial stations and a decrease of mean frequency with increased distance. Spectral amplitude ratios of equidistant stations on rock and alluvium emphasized the lower frequency content of the stations on alluvium. Pseudo–velocity response spectra envelopes indicated that more seismic energy was recorded at stations on deep alluvium than those on hard rock.

54 (PNE-5006) TRACE ELEMENTS IN COMMON ROCK TYPES AND THEIR RELATIVE IMPORTANCE IN NEUTRON-INDUCED RADIOACTIVITY CALCULATIONS. Paul, Roger A.; Day, Walter C. (Army Engineer Nuclear Cratering Group, Livermore, Calif.). June 1966. Contract W-7405-eng-48. 31p. Dep. mn.

The chemical composition of the rock surrounding an underground nuclear detonation must be known or assumed when calculations of the resulting neutron-induced radioactivity are attempted. A typical chemical analysis of rock samples does not include certain trace elements which have high neutron-capture cross sections. A literature search was undertaken to determine the average and range of content of these trace elements in common rock types to permit an evaluation of their relative importance in neutron-induced radioactivity calculations. The elements considered in the study were Dy, Gd, Eu, Sm, Nd, Cd, Ag, Co, Cr, V, Sc, Cl, S, B, and Li. Data are reported giving contents of these elements in ten igneous rock types and three sedimentary rock types. The five elements Gd, Eu, Sm, B, and Cl were found to occur in most rock types in quantities which would significantly affect neutron-induced radioactivity calculations. Calculations of induced radioactivity were performed for granite using maximum, average, and minimum trace element values obtained from the literature search. Calculations were also performed using average trace element values for four other igneous rocks and two sedimentary rocks. It is concluded that, in general, use of the average values for trace elements presented in this report is adequate for assessing the production quantities of radionuclides induced external to the device for use in feasibility studies for large scale excavation projects and other underground nuclear detonations when detailed chemical analyses of emplacement media are not available.

55 (PNE-5008) DISTRIBUTION OF SELECTED TRACE ELEMENTS IN ROCKS. Kley, Ronald J. (Army Engineer Nuclear Cratering Group, Livermore, Calif.). Feb. 27, 1968. Contract W-7405-eng-48. 68p. Dep.

Factors influencing trace element distribution in rocks, tables of maximum and minimum concentrations of twenty-nine trace elements in various common rock types, and descriptions of the geochemical behavior of each of these elements are presented. A procedure is outlined for predicting concentrations of these selected elements in various rock types. Trace element concentration varies systematically according to the gross mineralogical composition of the host rock. Mineralogical composition of the host rock is the primary determinant of trace element concentrations. Knowledge of rock mineralogy as provided by conventional petrographic analyses serves as a basis for estimating trace element concentrations.

56 (SC-4903(RR)) HUGONIOT DATA FOR SOME GEOLOGIC MATERIALS. Bass, R. C.; Hawk, H. L.; Chabai, A. J. (Sandia Lab., Albuquerque, N. Mex.). June 1963. Contract AT(29-1)-789. 19p.

Hugoniot data were obtained for several geologic solids including porous soils and porous and nonporous rocks. Effects of porosity and water content on Hugoniots of porous materials were examined. Experiments conducted with a highly homogeneous, chemically pure silica sand indicate that porosity and water content significantly alter the Hugoniots of porous materials. For a given shock disturbance, constant increase in internal energy imparted by a shock wave, shock pressure will increase as porosity is decreased and as water content is increased.

57 (SC-RR-64-1756) SOUND RAYS IN THE ATMOSPHERE. Thompson, R. J. (Sandia Corp., Albuquerque, N. Mex.). Jan. 1965. Contract AT(39-1)-789. 12p. Dep. (mn).

A system of ordinary differential equations governing ray paths in the presence of winds is derived and discussed. The equations are derived under the assumption that the winds and the speed of sound depend only on altitude. The results are compared with several methods that have been used for finding ray paths approximately.

58 (SC-RR-66-415) COMPARISON OF AIR BLAST FROM TWO SIZES OF ROW CHARGES. Vortman, L. J. (Sandia Corp., Albuquerque, N. Mex.). Oct. 1966. Contract AT(29-1)-789. 33p. Dep. mn.

Air blast as a function of distance was measured from the end of, and perpendicular to, a row of five 64-pound charges at the same cube-root scaled burial depth and spacing as in project Dugout, but in dry-lake playa rather than in basalt. Wave forms had similar conformation but differences in amplitudes and times in the two events; azimuthal variations also were different. The results suggest that the blast phenomena from row charges may scale as a smaller-than-$\frac{1}{3}$ power of the charge weight when burial depth and spacing are scaled by cube root. This result is contrary to the adherence to cube-root scaling found for air blast from buried single charges. In view of differences in media, dissimilarities in amplitudes and times, and azimuthal variations, with data from only two detonations to work with, too much credence should not be placed in these findings until additional events substantiate them.

59 (SC-RR-66-548) ADDITIONAL HUGONIOT DATA FOR GEOLOGIC MATERIALS. Bass, Robert C. (Sandia Corp., Albuquerque, N. Mex.). Oct. 1966. Contract AT(29-1)-789. 29p. Dep. mn.

Hugoniot equation-of-state data were obtained for several additional geologic materials. Included were andesite, volcanic breccia, granite, limestone, oil shale, tuff, and alluvium.

60 (SC-RR-67-24) STUDY OF THE MECHANICS OF SLIDE DAMS WITH SAND MODELS. Young, George A. (Michigan Technological Univ., Houghton. Dept. of Civil Engineering). Apr. 1967. Contract AT(29-1)-789. 107p. Dep.

Results of experimental laboratory work performed to study the effects of valley and slide geometry on model dam profiles are presented. Some consideration was also given to the physical properties of the slide materials. Two idealized experimental models were used. The first, a plane motion model, simulated the geometric characteristic of a deep, narrow valley when slides are initiated high on each valley wall slope. The second, a three-dimensional model, simulated the conditions in more typical valleys, where the wall slopes have an inclination with the horizontal of from 45 to 75 degrees. Model studies were restricted to small scales in which sand-size grains of quartz, or magnetite, were used as the slide material. Geometric scaling was done through three ratios of dimensions. Ratios for the plane motion experiments were 1 : 2 : 3 with a maximum height of fall of 6 feet. For the three-dimensional experiments, ratios were 1 : 1-$\frac{1}{2}$: 2 with a maximum slope length of 4 feet. Consideration was also given to different variables. Variables considered in the plane motion experiments were volume of slide material, width of slide, height of fall, and physical properties of the slide material such as angle of internal friction, particle size, and particle density. In the three-dimensional studies the angle of inclination of the valley wall slope was also considered. Tests were performed with both models to determine the effectiveness of revetments in controlling critical dimensions of dam profiles. Results indicate that model profiles can be scaled with reasonable success. The width of the slide was found to be one of the most important geometric variables which the designer can control. Particle size was found to be a significant variable. Angle of internal friction and particle density were not proven to be significant variables in the plane motion studies where slide particles have relatively high velocities. The former was found more significant in the three-dimensional studies, where slower particle velocities resulted. Revetments were not found effective. Confidence is expressed that a model study for a given site will reveal the crater configuration required to produce the most favorable dam geometry. Reasonable predictions of slopes, base width, and crest height of dam can also be provided.

61 (SC-RR-67-53) COMPUTING SOUND RAY PATHS IN THE PRESENCE OF WIND. Thompson, R. J. (Sandia Corp., Albuquerque, N. Mex.). Feb. 1967. Contract AT(29-1)-789. 30p. Dep. mn.

A FORTRAN 63 program for computing sound ray paths in the presence of winds is discussed. A listing of the program is included. The program also computes for each ray a quantity which indicates how the pressure at the point where the ray strikes the ground is affected by meteorological conditions. A discussion of how this quantity is defined and computed is included.

62 (TID-24191) GROUTING IN SUPPORT OF UNDERGROUND NUCLEAR TESTING. Miscellaneous Paper No. 6–914. Bendinelli, R. A.; Burnett, W. L. (Army Engineer Waterways Experiment Station, Vicksburg, Miss.). Apr. 1967. Contract AT(29-2)-752. 29p. Dep.

The development and the placement of grouts in support of underground nuclear experiments are described. Support consists of consultation services for grouting programs; development of grout mixtures to meet experimental requirements, i.e., stemming of nuclear devices in deep drilled holes; coupling to formations associated instrumentation emplaced in deep holes drilled in various rock and alluvium formations; as massive plugs in shafts and tunnels; as shock-mitigation material behind tunnel liners, etc. Problems experienced and resolution of such problems are described.

63 (UCID-5033) SOC: A NUMERICAL MODEL FOR THE BEHAVIOR OF MATERIALS EXPOSED TO INTENSE IMPULSIVE STRESSES. Seidl, F. G. P. (California Univ., Livermore, Lawrence Radiation Lab.). July 9, 1965. Contract W-7405-eng-48. 191p. Dep. mn.

A Lagrangian computer code known as SOC is described. This code is used to predict the reactions of media to impulsive forces; it was designed primarily to calculate the results of underground nuclear explosions. Some aspects of the code have been verified experimentally; namely, the hydrodynamic and the elastic modes of material response. Although restricted to one dimension, e.g., plane, cylindrical, or spherical symmetry, SOC can be used to model more modes of solid behavior than any other known code. Beside being able to treat free-running shocks by means of the von Neumann-Richtmyer artificial viscosity, the program includes: compressible flow, shock vaporization, shock melting, crushing, compaction, repeated opening and closing of cracks in one or two principal directions or both, combined plastic-elastic behavior, elastic behavior, and chemical detonations. In addition, the tests for plastic flow and crushing can depend upon rate of strain. Experimental confirmation of some of the above specified SOC-model processes for rock materials is not available. The necessary physics understanding and experimental inputs are in some cases not well known. Driving forces are introduced by an idealization of the violent expansion of a localized region of extremely hot gas, from a prescribed pressure-profile, and through numerically simulating detonation of a chemical explosive. Two types of output are available: periodic printouts of the variables of active zones, and plots of variables as a function of time at 25 material points. Consideration is also given to the basis for employing an artificial viscosity. The question of computational stability is examined in some detail.

64 (UCID-15283) STRESS HISTORY MEASUREMENTS: HARDHAT EVENT. Heusinkveld, M.; Holzer, F.; Marks, R.; Harris, D. (California Univ., Livermore. Lawrence Radiation Lab.). Mar. 1962. Revised Feb. 1968. Contract W-7405-eng-48. 14p. Dep.

The Hardhat Event was detonated on February 15, 1962, at the Nevada Test Site. The nuclear device was placed at a depth of 950 feet in a granite medium. The dynamic stress in the rock was measured by means of transducers located at approximately this depth and at distances of 200, 350, and 700 ft from the point of detonation. The stress curves were plotted and compared with theoretical predictions.

65 (UCRL-12065(Pt.2)) LABORATORY VERIFICATION OF EXPLOSION CALCULATIONS. PART II. Hearst, Joseph R. (California Univ., Livermore. Lawrence Radiation Lab.). Aug. 31, 1966. Contract W-7405-eng-48. 20p. Dep. mn.

A small-scale "row-charge" experiment was performed with three 2-cm high-explosive charges 9 cm apart on centers and 12 cm below the surface of a tank of the very viscous fluid polyisobutylene. Interaction of the cavities was studied, and cavity growth, free surface motion and pressure versus time were compared with the results of a calculation with the two-dimensional hydrodynamic elastic-plastic computer code TENSOR. Agreement was good except for pressure. Motion of the material between adjacent charges was studied to investigate whether a "row charge" could be approximated by a horizontal cylindrical charge. The approximation is poor.

66 (UCRL-12125) PREDICTION OF FALLOUT FROM SUBSURFACE NUCLEAR DETONATIONS. Knox, Joseph B. (California Univ., Livermore. Lawrence Radiation Lab.). Oct. 14, 1964. Contract W-7405-eng-48. 37p. (CONF-765-5). Dep. (mn).

From 2nd Conference on Radioactive Fallout from Nuclear Weapons Tests, Germantown, Md., Nov. 1964.

A numerical simulation model has been developed for the predictions of fallout from subsurface nuclear detonations that produce craters through spall and the action of the cavity gas. The physical processes modeled are atmospheric transport, lateral eddy diffusion, and gravitational sedimentation of radioactive particulates. This "cratering fallout model" is normalized to the observed external gamma dose rate fields of the Sedan (100-kt) and Danny Boy (0.43-kt) cratering events conducted at the Nevada Test Site. Calculations of the fallout patterns for additional events, used for testing the prediction capability of the cratering fallout model, indicate that the model gives estimates of the external gamma dose rate at H + 1 hours with a maximum error of a factor of 2 to 3 in the gamma dose rate versus distance along the hot line of the pattern.

67 (UCRL-13225) NEAR-SURFACE SPALLING FROM A NUCLEAR EXPLOSION IN A SALT DOME. Eisler, J. D. (Stanford Research Inst., Menlo Park, Calif.). [1966]. Contract W-7405-eng-48. 32p. Dep. mn.

Although near-surface spalling observed on the Salmon nuclear shot resembled that observed on other shots in different environments, the spalling process was more complex because of an artificially filled platform at surface zero. The Salmon maximum spall gap width (0.1 m) in the vicinity of surface zero was roughly $\frac{1}{6}$ of that which would be expected without the platform. The radius was 460 m, and the spalled layer thickness was 11.7 m. Measurements established that the near-surface layers had experienced multiple bouncing rather than successive spallation.

68 (UCRL-13334) STRENGTH PROPERTIES OF ROCK IN TRIAXIAL COMPRESSION. Smith, James L.; DeVries, K. Lawrence; Bushnell, Dwight J.; Brown, Wayne S. (Utah Univ., Salt Lake City. Dept. of Mechanical Engineering). Sept. 1967. Contract P. O. 5921803. 50p. Dep.

For Univ. of California, Livermore.

Test results are reported from triaxial compression experiments on sandstone, granite, marble, and shale specimens with the hydrostatic confining pressure varying from atmospheric pressure to a maximum of 90,000 psi corresponding to a mean stress of 143,000 psi. Stress measurements were made with a load cell incorporated into the loading piston and axial strain was measured inside the pressure vessel with a linear variable differential transformer developed for the experiments. Results are presented in the form of stress-strain curves for individual specimens and maximum shear stress vs mean stress curves for each material. A number of tests made with granite specimens which had been previously fractured showed that if the confining pressure was above 30,000 psi the precracked specimens exhibited behavior similar to intact granite.

69 (UCRL-14700) WASHOUT OF PARTICULATE MATTER IN LONG-TERM CLOUDS PRODUCED BY NUCLEAR EXPLOSIONS. Petersen, Allen H. (Lawrence Radiation Lab., Univ. of California, Livermore). Mar. 14, 1966. Contract W-7405-eng-48. 24p. Dep. mn.

The theory of rain-scavenging of airborne particulate matter is extended to the more general case of moving, polydisperse populations. Values for a multidimensional washout coefficient as a function of particle radius and rain intensity are given. By using expressions for the concentration within an instantaneous point source cloud with a spectrum of particle sizes, formulas are derived which give the rate of deposition and integrated deposition of radioactivity or particles from a long-term nuclear device cloud at any point downwind. Two important meteorological situations which may occur during washout are analyzed separately. The general expressions show that in a longterm nuclear device cloud, both the rate of deposition and integrated deposition are functions of the following independent variables: radius of the device cloud in the direction of the wind speed; wind speed, or speed of the cloud relative to the rain-producing layer; shape of the cloud's concentration; distance downwind; and rain intensity. By employing recent empirical data for the distribution of radioactivity with particle size within the cloud from the Sedan event, the equations are used to calculate the maximum integrated deposition of radioactivity which might be scavenged from long-term clouds produced by a nuclear device used for excavation.

The maximum percentage of the cloud's radioactivity deposited within the first meter is presented nomographically with various wind speeds in miles per hour and rain intensities in millimeters per hour. (33 references).

70 (UCRL-14702) DEPOSITION VELOCITIES OF AEROSOLS AND VAPORS ON PASTURE GRASS. Fisher, H. Leonard (Lawrence Radiation Lab., Univ. of California, Livermore). Mar. 14, 1966. Contract W-7405-eng-48. 20p. Dep. mn.

Predictive models of vapor and aerosol particle deposition velocities on grass surfaces are presented both as equations and as parametric curves that illustrate the relationship between the deposition velocity and such factors as wind speed, terrain roughness, and the terminal velocity of particles. Comparison is made with experimental results under known conditions and it is demonstrated that vapor deposition velocity can be predicted to within a factor of 3, while particle deposition velocity can be predicted to a factor of 2 or better, the accuracy increasing with increasing particle size. The deposition velocity of fallout debris was calculated both for deposition on pasture grass and fallout collectors (pot or gummed-film) at wind speeds on the order of 10 mph. These calculations indicate that the deposition velocity on pasture grass for vapors and small particles is approximately three times as great as the deposition velocity on the fallout collectors. For particles 20 microns in diameter, the calculated values are the same for both types of surfaces.

71 (UCRL-14707) ESTIMATION OF DOSAGE TO THYROIDS OF CHILDREN IN THE U. S. FROM NUCLEAR TESTS CONDUCTED IN NEVADA DURING 1952 THROUGH 1955. Tamplin, Arthur R.; Fisher, H. Leonard (Lawrence Radiation Lab., Univ. of California, Livermore). May 10, 1966. Contract W-7405-eng-48. 53p. Dep. mn.

Estimates of the thyroid dosage accumulated by children up to 5 years of age in the United States as a result of nuclear weapons tests in Nevada during 1952 through 1955 are reported. The estimates are based upon the assumption that the children were consuming 1 liter of milk per day from cows on pasture. It is not known to what extent this assumption is valid. The data, the analytical approach, and the assumptions inherent to the analysis are presented, together with the estimates.

72 (UCRL-14711) STATIC PV CURVES OF CRACKED AND CONSOLIDATED EARTH MATERIALS TO 40 KILOBARS. Stephens, D. R.; Lilley, E. M. (California Univ., Livermore. Lawrence Radiation Lab.). Mar. 28, 1966. Contract W-7405-eng-48. 68p. (CONF-660451-1). Dep. mn.

From Conference on Shock Metamorphism of Natural Materials, Greenbelt, Md.

The hydrodynamic codes used to calculate the effects of underground explosions for the Plowshare Program require the equations of state of the rock in which the explosion takes place. The PV curves of the rock to 40 kilobars at 25°C were measured. Since the PV curve of the rock changes when the rock is cracked by the shock, a method was developed to obtain the corresponding values for the cracked material. The basic equipment and technique for data on consolidated materials are the same as those described by P. W. Bridgman and by G. C. Kennedy. The specimen is cracked by pressurizing it in a piston-cylinder die with a faulty piston until the piston breaks. The sudden release of pressure when the piston fails breaks the sample by tensile fracture. The broken piston is removed from the die; a new piston is inserted, and data are taken with the cracked specimen. The "cracked" and "consolidated" equations of state for materials of interest to Plowshare ranging from sand to single crystals have been obtained. For the loading curve (increasing pressure) there are essentially two types of behavior. Cracking a porous material allows it to compress to a smaller volume (at constant pressure) than the solid. Cracking apparently is effective in breaking the rigidity of the porous compact so that it will compact more efficiently. In contrast, cracking a dense rock produces a larger volume at equal pressure. At a sufficiently high pressure, the consolidated and the cracked curves become identical. This sort of behavior is related to the porosity induced by cracking and to the porosity of the consolidated rock. Using the model developed by Walsh for the effect of crack porosity on compressibility, the qualitative features of the PV curves are accounted for.

73 (UCRL-14729) GAS EQUATION OF STATE FOR NATURAL MATERIALS. Butkovich, T. R. (California Univ., Livermore. Lawrence Radiation Lab.). Jan. 24, 1967. Contract W-7405-eng-48. 25p. Dep. mn.

Gas equations of state have been developed for materials in which nuclear detonations have occurred; H_2O, NaCl, and silicate rocks. For silicate rocks, a simple silicate approximation was used; the rock gas was assumed to consist of SiO_2 plus varying amounts of H_2O by weight. The model assumed SiO_2 + 1% H_2O constituted dry rock, SiO_2 + 10% H_2O constituted partially saturated rock, and SiO_2 + 20% H_2O constituted a fully saturated porous rock. The materials are treated as a perfect gas of molecules and ions to temperatures of about 3 eV (1 eV ≃ 11,600°K) and less than normal density. Above this temperature the gas is described in terms of atoms and ions up to the point where it is completely ionized and consists of nuclei and free electrons. Above normal density, the shock Hugoniot equation of state was used. Expansion adiabats were calculated for the various gases, using a number of simplifying assumptions. Also the relationships between the amount of material vaporized and the energy yield were obtained. From data on a number of contained nuclear explosions, relationships between measured cavity volume and overburden pressure were obtained. These relationships show that for contained explosions the cavity expands until its pressure equals some factor greater than the overburden pressure ρgh, depending on the material. This factor varies from 1.3 to 2.3, and indicates that the material outside the gas maintains a residual shear strength.

74 (UCRL-14739(Pt.2)) PROGRAM BOOK FOR THE ADVISORY COMMITTEE FOR BIOLOGY AND MEDICINE OF THE UNITED STATES ATOMIC ENERGY COMMISSION. PART II. (Lawrence Radiation Lab., Univ. of California, Livermore). Mar. 10, 1966. Contract W-7405-eng-48. 177p. Dep. mn.

Studies are reported on: radionuclide metabolism in man and other organisms; biochemical and metabolic reactions; the effects of ionizing radiation on biosynthesis and genetics; radionuclide burdens in man and the terrestrial environment; biological ultrastructure; particulate behavior and fallout deposition; and radiation detectors and monitoring systems.

75 (UCRL-14922) A GRAPHICAL METHOD FOR CALCULATING THE DOSE IN MAN FROM INDIVIDUAL RADIONUCLIDES IN FALLOUT. Burton, C. Ann (Lawrence Radiation Lab., Univ. of California, Livermore). June 3, 1966. Contract W-7405-eng-48. 20p. Dep. mn.

The fallout deposition required to deliver a specific integrated 30-yr dose to any tissue in man, for any and all radionuclides in a single event, is presented in graphical as well as analytical form. The model used is consistent with the data that are available to this problem at the present time. A table of effective tissue half-lives for given radiological and biological half-lives is given for use with the graphs. Sample calculations are also included.

76 (UCRL-14983) PREDICTING AND SAMPLING NUCLEAR CLOUDS FROM THE VIEWPOINT OF DIFFUSION THEORY. Crawford, Todd V. (California Univ., Livermore, Lawrence Radiation Lab.). Apr. 29, 1966. Contract W-7405-eng-48. 42p. Dep. mn.

The distribution in time and space of pollutants from a large explosion is a function of the motion of the cloud relative to a coordinate system fixed on the earth's surface, and the change of the pollutant distribution within a coordinate system that travels with the cloud center. This study is concerned with only the second problem within a time scale of a few days and a space scale of a few kilometers to a few hundred kilometers. The present network of upper air observation stations is so coarse, relative to the dimensions of the clouds of interest, that it is not possible to predict the relative horizontal movement of the cloud (with respect to the cloud center) in a deterministic manner. Therefore, a diffusion model has to be used. Thus, it is appropriate to examine the consequences of using a diffusion theory on these time and space scales. The frequently observed Gaussian distributions, used in micrometeorological studies of continuous point sources, are a consequence of long sampling time compared to the time scale of diffusion processes. However, kilometer-sized clouds are sampled by aircraft in a time period which is short compared to the time scale of the diffusion processes. Therefore, it should not be expected that any one flight through a cloud would give concentration data, as a function of distance along the flight path, in agreement with the smooth Gaussian type of distributions predicted by diffusion theories. The more the cloud concentration data are smoothed after collection, the more likely is any one cloud's time-and-space history to follow a diffusion theory prediction better than any one cloud. The average of many clouds will fit diffusion theory prediction better than any one cloud. Assuming an idealized Gaussian cloud, a number of numerical calculations are made to illustrate the consequences of different methods

of sampling. Along flight path, concentration data needs to be obtained with a spacial resolution equivalent to the standard deviation of the cloud (in distance) at the time of sampling. To investigate diffusion by looking at cloud growth, the isopleth of concentration used to define the cloud boundary must be four to five orders of magnitude below the initial peak concentration, or the isopleth of radioactivity (with a decay proportional to t^{-1}) must be eight to nine orders of magnitude below initial peak concentration. It is suggested that several aircraft be used to sample these clouds. One airplane should keep continuous track of the cloud boundary and direct the sampling efforts of the other aircraft. If careful control of aircraft sampling technique is not maintained, it is unlikely that one will be able to use data to distinguish between the predictions of different diffusion theories. The smoothing problems illustrated by the various numerical computations in this report will give the appearance of slow diffusion. Cloud location problems, effects of mean wind shear, and depletion due to fallout, wipe out, rainout, and washout would give the appearance of fast diffusion.

77 (UCRL-50142) LITHOLOGY AND GEOPHYSICAL PROPERTIES OF THE "GREELEY" MEDIUM. Meyer, G. Lewis; Rambo, John (California Univ., Livermore. Lawrence Radiation Lab.). Oct. 25, 1966. Contract W-7405-eng-48. 37p. Dep.

The Greeley experiment is located on Pahute Mesa, Area 20, of the Nevada Test Site. Two exploratory holes penetrated volcanic rocks of Tertiary age consisting of interbedded welded tuffs, zeolitized tuffs, and rhyolites. Interpretations of the lithology and geophysical properties of the Greeley medium were made from drill cuttings, core, hydrologic tests, petrographic analysis, and an extensive suite of geophysical logs. These different classes of information all seem valid and correlate well. The medium at 3600 to 4200 ft is interpreted as being relatively homogeneous, isotropic, and unfractured. Average properties of the medium include porosity, 30%; permeability, 2.5 millidarcies; density, 2.16 g/cm^3; temperature, 102°F; compressional velocity, 10,000 fps; and shear velocity, 4700 fps. The special problems incurred during geophysical logging in the volcanic rocks of the Nevada Test Site are discussed briefly for each type of log.

78 (UCRL-50149) MACRODEFORMATION RESULTING FROM THE HANDCAR EVENT. Boardman, Charles R.; Meyer, G. Lewis; Rabb, David D. (California Univ., Livermore. Lawrence Radiation Lab.). Dec. 1, 1966. Contract W-7405-eng-48. 54p. Dep. mn.

The Handcar event was a 12-kt nuclear explosion at a depth of 402.3 m in fractured dolomite. The explosion produced a cavity with a radius of 21.2 ± 0.8 m which collapsed within 17 seconds after the detonation. The resultant chimney of broken rock is slightly tilted and extends to a height of 68 m, or 3.2 times the cavity radius above the shot point. A void exists at the chimney apex with a height of 17.4 m and volume greater than 50% of the initial cavity volume. Rubble particles observed on the floor of this cavity range up to 1 m in diameter. 82% by volume of the observed particle diameters are in the range of 2.5 to 42.5 cm. The rock below the chimney appears to be highly crushed to a radial distance from shot point of 26–27 m. Also, data from the pressurization of the chimney are interpreted to indicate that the average permeability of the rock beyond the chimney has been increased to a radial distance of 3.5 to 5 cavity radii. The air temperature in the apical void of the chimney was 34.5°C (10°C above background) 12 months after the explosion. The first indication of a temperature rise above background was observed at a radial distance of 113 m above the shot point. The maximum observed radial extent of increased gamma radiation above background was about 94 m above the shot point.

79 (UCRL-50150) A MEASUREMENT OF THE VOLUME OF VOID IN THE SHOAL CHIMNEY. Boardman, Charles R. (California Univ., Livermore. Lawrence Radiation Lab.). Sept. 27, 1966. Contract W-7405-eng-48. 12p. Dep. mn.

Air pressurization tests conducted on the Shoal chimney indicate a chimney void volume of $80{,}400^{+3600}_{-4700}$ m^3. Assuming that the cavity was spherical at time of collapse and that all its void was translated into the chimney, its radius was $26.8^{+0.4}_{-0.5}$ meters based on this measurement. This value is consistent with an interpretation of temperature data from the region below shot point.

80 (UCRL-50163(Pt.1)) PREDICTION OF THE MAXIMUM DOSAGE TO MAN FROM THE FALLOUT OF NUCLEAR DEVICES. I. ESTIMATION OF THE MAXIMUM CONTAMINATION OF AGRICULTURAL LAND. Tamplin, Arthur R. (California Univ., Livermore. Lawrence Radiation Lab.). Jan. 3, 1967. Contract W-7405-eng-48. 28p. Dep. mn.

A semi-empirical approach toward estimating the maximum contamination of agricultural land by radionuclides produced by nuclear devices is presented. It is based upon the maximum fallout levels observed subsequent to all previous tests of nuclear devices and applies to cloud travel times or fallout arrival times ranging from 1 to 50 hr and beyond.

81 (UCRL-50163(Pt.2)) PREDICTION OF THE MAXIMUM DOSAGE TO MAN FROM THE FALLOUT OF NUCLEAR DEVICES. II. ESTIMATION OF THE MAXIMUM DOSE FROM INTERNAL EMITTERS. Ng, Yook C.; Thompson, Stanley E. (California Univ., Livermore. Lawrence Radiation Lab.). Dec. 14, 1966. Contract W-7405-eng-48. 25p. Dep.

A method is described for estimating the maximum internal dose that could result from the deposition of fallout radionuclides released to the atmosphere. By means of this analysis one can identify the nuclides that could contribute most to the internal dose, and determine the contribution of each nuclide to the total dose. The biological exchangeable pool concept was used for the analysis. Using this approach, the passage of a radionuclide through the biosphere is presumed to be governed by the same factors that govern the distribution of the related stable isotopes within the biological exchangeable pool. It must be assumed, of course, that the radionuclide is biologically no more available than the related stable isotopes within the environment. The basic calculation required is an estimation of the unit-rad deposition for each radionuclide encountered. The unit-rad deposition F_1 is the minimum deposition that could result in a 30-year internal dose of 1 rad. Estimated maximum doses are calculated from F_1 and from known or predicted values of deposition. Two modes of entry into man are assumed: direct deposition on forage leading into the forage-to-cow-to-milk pathway, and deposition on the terrain followed by equilibration in the biological exchangeable pool, for which the soil-root pathway is required for entry into plants. The method is illustrated by calculations required to estimate the maximum 30-year internal dose to the whole body.

82 (UCRL-50163(Pt.3)) PREDICTION OF THE MAXIMUM DOSAGE TO MAN FROM THE FALLOUT OF NUCLEAR DEVICES. III. BIOLOGICAL GUIDELINES FOR DEVICE DESIGN. Burton, C. Ann; Pratt, Michael W. (California Univ., Livermore. Lawrence Radiation Lab.). July 25, 1967. Contract W-7405-eng-48. 17p. Dep.

A method has been developed to estimate the biological hazard due to the radioisotopes that result from reactions between nuclear device components and the particles released by the device. This method can be used in preshot rad-safe analysis, as guidance for postshot documentation, and in the choice of the most biologically suitable elements for device design. As an example of the technique, tungsten was studied in detail. It was found that, in tungsten, the charged-particle reaction products may be the largest contributors to the biological hazard from this element.

83 (UCRL-50164) AVAILABLE DISINTEGRATION ENERGY OF ALL RADIONUCLIDES (FOR USE IN DOSIMETRY PROBLEMS). I. HALF-LIVES 12 HOURS OR GREATER. Burton, C. Ann.; Maxwell, Joan H. (California Univ., Livermore. Lawrence Radiation Lab.). Dec. 15, 1966. Contract W-7405-eng-48. 34p. Dep. mn.

The ERPD computer program calculates the maximum available energy per disintegration for all radionuclides. The input and the results are given for nuclides with half lives greater than 12 hours.

84 (UCRL-50177) SOME CHARACTERISTICS OF THE HARDHAT CHIMNEY AND SURROUNDING WALL ROCK. Boardman, Charles R. (California Univ., Livermore. Lawrence Radiation Lab.). Oct. 1966. Contract W-7405-eng-48. 16p. Dep. mn.

The Hardhat event was a 4.9 ± 1.5 kt nuclear explosion at a depth of 286.2 meters in granodiorite. Data from three underground drill holes have been analyzed in an effort to further define chimney characteristics. The chimney radius was determined to be 20.3 m near shot point level and 17.7 m near the apical void. The earlier determined cavity radius of 19.2 m was confirmed. Total chimney volume is calculated to be 113,860 m^3, consisting of 30,800 m^3 of void space and 222 million kilograms of rock. Of the total chimney volume, 27% is void space. In the rubble column itself, exclusive of the apical void, 22% is void space. The nature of the radioactive melt and its distribution in

the puddle suggest that the cavity did not collapse until H + 11 hours when an audible rumble was heard. The zone of highly crushed rock outside the chimney is calculated to have a void volume of about 2500 m^3, roughly 8% of the void volume inside the chimney.

85 (UCRL-50179) COMPUTER PROGRAM FOR CALCULATING THE ATMOSPHERIC DISPERSION OF LARGE CLOUDS. Crawford, Todd V. (California Univ., Livermore. Lawrence Radiation Lab.). Nov. 23, 1966. Contract W-7405-eng-48. 58p. Dep. mn.

A numerical model is presented for predicting the time and space history of cloud concentrations, due to pollutants from explosions, within a coordinate system fixed to the cloud's center. Theories of atmospheric turbulence and diffusion are reviewed and evaluated for applicability to this problem. It is concluded that, if the sampling time is long compared to the characteristic time of the diffusion processes, similarity theories reasonably fit the available data. Similarity theory was used to predict the horizontal diffusion of a cylindrical cloud, but, in the numerical model, vertical diffusivity as a function of cloud height above the ground is a more realistic input. Calculations are presented to show the sensitivity of the calculations to initial cloud size, atmospheric dissipation, vertical diffusivities, and the removal of material from the cloud by deposition velocities. A sample problem is given.

86 (UCRL-50188) SHORT TIME INTERVAL FREQUENCY MEASUREMENTS OF A CONTINUOUSLY CHANGING SINE WAVE. Marks, R. E. (California Univ., Livermore. Lawrence Radiation Lab.). Feb. 27, 1967. Contract W-7405-eng-48. 11p. Dep. mn.

A system was developed to measure the frequency at 1-msec intervals of a sine wave which changed continuously from 25 to 300 kHz within a period of 70 msec. The data were desired in a computer input form. The equipment was developed and successfully used in routine data analysis. The apparatus consists of a series of logic modules. Each module contains a circuit or set of circuits such as a clock, four-bit counter, delay or set of gates which when combined formed the analytical system whose output was in IBM cards. The data were calculated digitally as the amount of time necessary for an integral number of cycles. The data are stored in a magnetic core memory. When the 128-word memory is full, the data are punched onto IBM cards. The system is simple and efficient to use. The accuracy in the stated frequency range is about 0.1%.

87 (UCRL-50203) EFFECT OF WATER CONTENT, YIELD, MEDIUM, AND DEPTH OF BURST ON CAVITY RADII. Higgins, G. H.; Butkovich, T. R. (California Univ., Livermore. Lawrence Radiation Lab.). Feb. 21, 1967. Contract W-7405-eng-48. 26p. Dep.

Cavities produced by nuclear explosions can be accurately described provided that water content, medium density, and explosive energy are known. The equation

$$R_C = 100\ \{[(\bar{\gamma}-1)W\ P_V(1/\dagger_{\gamma-1})] \div [(\rho h)^{(1/\dagger\gamma)}]\}^{(2/3)}$$

describes results of 46 nuclear detonations in tuff, alluvium, salt and granite to the accuracy with which the cavity radius and other variables can be determined. The adiabatic expansion coefficient, $\dagger\gamma$, depends strongly on the water content of the medium. There is no indication that cavity size depends on the strength of the rock medium in which the explosion is detonated.

88 (UCRL-50211) NECESSARY CONDITIONS FROM SIMILAR SOLUTIONS OF PROBLEMS OF TURBULENT-GAS DYNAMICS. Crowley, Barbara K. (California Univ., Livermore. Lawrence Radiation Lab.). Jan. 31, 1967. Contract W-7405-eng-48. 29p. Dep.

The quasi-one-dimensional conservation equations with friction, heat, and mass sources are considered. Necessary conditions for similar solutions of these equations are mathematically derived, and these conditions are verified by sample computer calculations.

89 (UCRL-50276) RESEARCH FOR UNDERSTANDING AND CONSTRUCTIVELY USING UNDERGROUND NUCLEAR EXPLOSIONS. Rodean, Howard C. (California Univ., Livermore. Lawrence Radiation Lab.). June 6, 1967. Contract W-7405-eng-48. 53p. Dep.

Unclassified research directed toward the understanding of underground nuclear explosion phenomena and constructive applications for nuclear explosions are described. Physical measurements of ground motion generated by explosions are used together with the equations of state, chemical and thermodynamic theory, and the laws of continuum mechanics to develop mathematical models used to predict explosion phenomena. Postshot exploration is necessary to determine the residual explosion effects, such as heat deposition, rock fracturing, and chimney formation. These explorations give physical and chemical clues that aid in the interpretation of the experiment. Furthermore, the residual effects are of interest in many engineering applications. Safety considerations include airblast and seismic motion that may damage property and radioactivity that may be a health hazard. Significant progress has been made in predicting airblast, ground motion, and radioactivity distribution. Nuclear explosions are intense sources of neutrons; therefore, experiments are conducted to measure neutron cross sections and to produce heavy elements. The heaviest nuclide produced to date has a mass number of 257. The seismic waves generated by nuclear explosions have been used by geophysicists for over two decades to determine the internal structure of the earth with a precision not possible with earthquakes. Finally, research is under way to relate the effects of an explosion to its intended use (in the petroleum industry, for example).

90 (UCRL-50295) STERLING EVENT: CLOSE-IN PHENOMENOLOGY MEASUREMENTS. Sisemore, Clyde J. (California Univ., Livermore. Lawrence Radiation Lab.). June 29, 1967. 27p. Dep.

The Sterling Event, the first decoupled nuclear shot in the underground detection program, was executed December 3, 1966, at a site near Hattiesburg, Mississippi. In the region near the cavity, measurements of stress history, cavity pressure, particle acceleration, and cavity collapse were made for use in defining and evaluating the parameters controlling the magnitude of the decoupling ratio. Data are presented for the accelerometers, one stress-history gage and the cavity-collapse transducer. Although the acceleration and cavity-collapse data are satisfactory, data from several gages were not recorded; these losses were primarily the result of an unusually large ground loop present in the electronics system.

91 (UCRL-50299) LONG-RANGE DIFFUSION OF THE NRX/EST EP-4A EFFLUENT CLOUD. Crawford, Todd V. (California Univ., Livermore. Lawrence Radiation Lab.). June 1967. Contract W-7405-eng-48. 49p. Dep.

The generation, movement, and diffusion of the effluent cloud produced by the NRX/EST EP-4A reactor experiment of March 25, 1966, are discussed. The meteorology data during the reactor run are presented and, in the absence of measurements, an estimate of the stabilized initial cloud height and size is made. Estimated cloud widths are consistent with data obtained from ground-mounted instrumentation. Based on radiosonde data, meteorological trajectories, and aircraft concentration measurements, the height and horizontal trajectory of the effluent cloud for two days following the reactor run is discussed. Initial size and time-dependent meteorological parameters along the trajectory are then used as input to a cloud diffusion calculation with 2BPUFF computer code. Comparison of calculations with data indicates agreement, within a factor of two, for air concentration out to two days, surface air concentration, dry deposition, vertical concentration profile shape, and cloud size. During the two days over which measurements and calculations are compared, the radioactive concentration at the cloud center decreased some seven orders of magnitude.

92 (UCRL-50373) CALCULATION OF FREE-FIELD MOTION FOR THE PILEDRIVER EVENT. Cherry, J. T.; Rapp, E. G. (California Univ., Livermore. Lawrence Radiation Lab.). Feb. 2, 1968. Contract W-7405-eng-48. 9p. Dep.

The results of a technique which seems to calculate adequately the free-field motion resulting from a contained explosive event in granite are presented. The calculation indicates that free-field motion from Piledriver was no greater than might have been expected. The significance of the extent of compressive cracking to chimney formation has been discussed. Finally, it is shown qualitatively that the returning tensile wave can have a significant effect on late-stage cavity growth. This, we feel, is the reason for the "larger-than-expected" cavity radius observed in the Piledriver Event.

93 (UCRL-50385) RESULTS OF AN EXPLORATION INTO THE TOP OF THE PILEDRIVER CHIMNEY. Boardman, C. R. (California Univ., Livermore. Lawrence Radiation Lab.). Oct. 1967. 27p. Dep.

A vertical exploratory hole, U15.01 PS #1V, was drilled into the top of the chimney formed by the Piledriver Event—a 61-kt underground nuclear shot in granitic rock. Measurements of

permeability made as the hole progressed indicate that the maximum vertical extent of increased permeability above the shot point may have been as high as 314.6 ± 11 meters or 7.1 ± 0.2 cavity radii. Chimney height was established at 272.2 meters or 6.2 cavity radii. Void volume in the chimney was determined by the pressurization technique to be 367,900 ± 6% cubic meters. This volume is equivalent to a sphere with a radius of 44.5 meters. These results are compared with those obtained from two other U. S. nuclear explosions in granitic rock, Hardhat and Shoal. Radii of sphered chimney void volumes scale directly with the cube root of the yield with an error of only 1%, whereas scaling based on the assumption of adiabatic cavity expansion to overburden pressure results in an error of 6%. Chimney heights scale directly with cavity radius within 20%.

94 (UCRL-50418) THE LONG RANGE DIFFUSION OF THE EFFLUENT CLOUD FROM THE PHOEBUS 1B EP-IV REACTOR TEST OF FEBRUARY 23, 1967. Crawford, Todd V. (California Univ., Livermore. Lawrence Radiation Lab.). Apr. 1968. 29p. Dep.

The movement and diffusion of the effluent cloud produced by the Phoebus 1 B EP-IV Event was tracked by aircraft for almost three days, and useful concentration measurements were obtained for almost two days. Pre- and post-run calculations were done with a computer code for large cloud diffusion using climatology and observed meteorology respectively. Calculations of concentrations and cloud size are compared with the available measurements. Calculations agree well with measurement for the first few hours. At later times, comparisons of measured and calculated concentrations and cloud size indicate that calculations yielded concentrations a factor of 2 to 5 higher than observed. The most likely explanation is the presence of a large amount of change with height through the depth of the cloud of the mean wind direction. The increased dilution rate due to this effect is not included in the calculational model. In this sense calculations will be conservative. A contributing cause of this difference may also be insufficient resolution in the aircraft data at late time. During the two days of interest, decay and diffusion decreased radioactive concentration more than eight orders of magnitude.

95 (UCRL-50420) TERRAIN CORRECTIONS FOR BOREHOLE GRAVIMETRY. Hearst, J. R. (California Univ., Livermore. Lawrence Radiation Lab.). Apr. 30, 1968. 12p. Dep.

A computer program for the application of terrain corrections to borehole gravimetry measurements is described. The method involves the acquisition of the average elevations in each compartment from topographic maps. It would be possible to "read" the maps with a computer flying-spot scanner, but the effort involved in preparing suitable maps and programming would be much greater than that involved in hand-reading. A listing of the FORTRAN program MORIA is given. The code was checked against Hammer's surface corrections and found to be correct.

96 (UCRL-70540) ATMOSPHERIC DIFFUSION OF LARGE CLOUDS. Crawford, Todd V. (California Univ., Livermore. Lawrence Radiation Lab.). Sept. 12, 1967. Contract W-7405-eng-48. 29p. (CONF-670931-11). Dep.

From USAEC Meteorological Information Meeting, Chalk River, Ontario, Canada.

Clouds of pollutants travel within a coordinate system that is fixed to the earth's surface, and they diffuse and grow within a coordinate system fixed to the cloud's center. An approach is discussed for predicting the cloud's properties, within the latter coordinate system, on space scales of a few hundred meters to a few hundred kilometers and for time periods of a few days. A numerical cloud diffusion model is presented which starts with a cloud placed arbitrarily within the troposphere. Similarity theories at atmospheric turbulence are used to predict the horizontal diffusivity as a function of initial cloud size, turbulent atmospheric dissipation, and time. Vertical diffusivity is input as a function of time and height. Diurnal variations of turbulent diffusion in the boundary layer and effects of temperature inversions, etc., can be modeled. Nondiffusive cloud depletion mechanisms, such as dry deposition, washout, and radioactive decay, are also a part of this numerical model. An effluent cloud, produced by a reactor run at the Nuclear Rocket Development Station, Nevada, is discussed. Measurements on this cloud, for a period of two days, are compared to calculations with the above numerical cloud diffusion model. In general, there is agreement, within a factor of two, for airborne concentrations, cloud horizontal area, surface air concentrations, and dry deposition as airborne concentration decreased by seven orders of magnitude during the two-day period.

97 (UCRL-Trans-10145) CONNECTION BETWEEN THE RADIUS AND THE DURATION OF EXISTENCE OF THE CAVITIES CAUSED BY UNDERGROUND NUCLEAR EXPLOSIONS. Duclaux, F.; Derlich, S.; Faure, J.; Ferrieus, H.; Perrier, M. Translated by F. D. Jones for Univ. of California, Lawrence Radiation Lab., Livermore, from Compt. Rend., Ser. A and B, 264: 496-7(1967). 6p. Dep.

An explanation of the linear relationship between the radius of the cavity formed by an underground nuclear explosion and the time elapsing from the explosion to the collapse of the roof of this cavity is presented. The law is based on experiments carried out in granite massif. Deviation between the low and representative points is slight. The relative deviation is not more than 6%. Accuracy obtained by drilling the cavity and making direct measurements is of the same order.

98 (VUF-1025) PROJECT DRIBBLE-SALMON EVENT ON-SITE HEALTH AND SAFETY REPORT. Tappan, J. Tell; Moore, William E. (comps.) (Reynolds Electrical and Engineering Co., Mercury, Nev. Radiological Sciences Dept.). Nov. 1965. Contract AT(29-2)-162. 56p. Dep. mn.

The Salmon Event was detonated at the Atomic Energy Commission's Project Dribble Test Site, Tatum Salt Dome, near Hattiesburg, Mississippi, on October 22, 1964, to test improved instrumentation and explore procedures for detecting underground nuclear detonations. Radiation measurements were recorded during and after the detonation by a remote area monitoring system. After the detonation, radiation monitors equipped with portable radiation detection instruments surveyed the route into surface ground zero before other planned reentries were made. Continuous surveillance was provided while personnel were in the area. Radiological sciences requirements included: recording measurements of gamma dose rates; measurements of radionuclide concentrations in air; measurements of radionuclide concentrations in water; toxic gas and explosive mixture measurements; portable instrument measurements of gamma dose rates; and portable instrument measurements of alpha radiation. Only background radiation measurements were observed from zero time until communication with the cavity was established during postshot drilling operations at a depth greater than 2600 feet. Fifty-two individuals received radiation doses in excess of 100 mrem during the Salmon Event program. The maximum accumulated individual dose was 1065 mrem.

99 (VUF-1041) PRESHOT AND POSTSHOT SAFETY SURVEY OF OIL AND GAS FACILITIES, BAXTERVILLE FIELD, MISSISSIPPI: STERLING EVENT. Ward, Don C. (Bureau of Mines, Bartlesville, Okla. Bartlesville Petroleum Research Center). Jan. 1967. 78p. Dep.

A survey was made to evaluate any physical changes in oil and gas wells resulting from the detonation of the Sterling Event. Structures within a 5-mile radius of ground zero were examined and photographed. Other selected structures within a 6-mile radius were examined and photographed. The preshot and postshot survey indicates that no damage occurred to any oil or gas well or related facilities.

100 (VUF-3016) VENT-GAS TREATMENT PLANT. Project DRIBBLE: SALMON EVENT. Final Report. Snoeberger, D.; Heckman, R. (eds.) (Lawrence Radiation Lab., Univ. of California, Livermore). Mar. 1966. Contract W-7405-eng-48. 18p. Dep. mn.

A vent gas treatment plant was designed for the Project Dribble Nuclear detonation in the Tatum Salt Dome near Hattiesburg, Mississippi. The process consists of a remotely operated gas scrubbing and filtering system with charcoal adsorption units incorporated with the filters. The system will take up to 200 ft^3/min of cavity gas mixed with 2,000 ft^3/min of air to dilute H. Effluent gas is discharged from a 150-ft stack after being mixed with 20,000 cfm of additional air. Liquid wastes from the scrubbers are stored in four 25,000-gal tanks for later disposal.

101 (VUF-3021) TIMING AND FIRING. Final Report. Project DRIBBLE, Salmon Event. Colman, J. M.; Planchet, R. P. (Edgerton, Germeshausen and Grier, Inc., Bedford, Mass.). Jan. 1965. 43p. Dep. mn.

Timing and firing services for the Salmon event of the Dribble Program are described. In addition to the Salmon event timing and firing services for two high-explosive confirmation experiments conducted under the technical direction of the Lawrence Radiation Laboratory are also described. All monitors at the control point indicated that the performance of the timing sys-

tem was completely satisfactory on both the Salmon event and the two confirmation experiments. Both hardwire and radio signals were transmitted to the experimenters as requested. Instrumentation for the Salmon event included (1) the special mobile control point built for the Dribble Program, (2) a zero site station housed in a wooden structure located in the area adjacent to surface zero, (3) radiotone barrels for use of experimenters located at positions remote from the control point, and (4) communications nets essential to the transmission of long-range, local, and worldwide countdown.

102 (VUF-3025) SUBSURFACE PHENOMENOLOGY MEASUREMENTS NEAR A DECOUPLED NUCLEAR EVENT. Project STERLING. Sisemore, Clyde J.; Rogers, Leo A. (California Univ., Livermore. Lawrence Radiation Lab.); Perret, William R. (Sandia Corp., Albuquerque, N. Mex.). Oct. 1967. 35p.

The Sterling Event, a 380-ton nuclear explosion detonated in a spherical cavity, was a test of decoupling theory for nuclear explosives detonated in explosively generated cavities. Primary objectives included determining the amount of decoupling and evaluating the effects of the altered salt on the decoupling ratio. Measurements of stress history, cavity pressure, and cavity collapse were made in the very close-in region near the cavity wall, and free-field measurements of particle velocity and acceleration were made in the immediate region surrounding the cavity. Accelerations were recorded at locations between 52 and 660 m and particle velocities at locations between 166 and 662 m as measured from the cavity center. Peak accelerations measured over this interval ranged from 150 to 0.2 g and peak velocities from 0.13 to 0.01 m/sec. Analysis of the reduced displacement potentials and their Fourier transforms obtained from Sterling and other tamped events yields a seismic source amplitude ratio of about 100 for a frequency range near 10 Hz. Above 10 Hz the ratio drops rapidly to about 20. These results are in reasonably good agreement with the decoupling theory, and they also verify the preshot theoretical calculations of the decoupling predicted for an explosively generated cavity.

II. EXCAVATION

A. APPLICATIONS

Published Literature

103 AN APPLICATION OF NUCLEAR EXCAVATION TO RAILROAD USE. Beeder, R. H. (Atchison, Topeka and Santa Fe Railway, Los Angeles, Calif.). Amer. Railway Eng. Ass. Bull., 67: 742-7(June-July 1966).

Project Carryall, a study to investigate the economic feasibility of using nuclear excavation to cut a channel 2 miles long through the Bristol Mountains in California to relocate a 78-mile segment of double-track railroad is described. The study, conducted by railway, highway, and government engineers, concluded that Project Carryall was technically and economically feasible. It was estimated that the use of nuclear explosions to excavate the channel would save about $8,000,000 over the cost of a route location by conventional construction methods.

Reports

104 (CONF-660114-1) NUCLEAR BLASTING AND ITS POTENTIAL FOR STRIPPING OVERBURDEN. Russell, Paul L. (Bureau of Mines, Washington, D. C.). Dec. 1965. 17p.

From 27th Annual Mining Symposium, Duluth, Minn.

The use of nuclear explosives for excavation was demonstrated to be feasible and practical. Application of nuclear explosives for overburden removal from large ore deposits appears to offer an economic advantage over present methods, but under the present pricing schedule, high-yield devices must be used to obtain an economic advantage. The use of nuclear explosives presents problems not inherent in the use of conventional explosives, thus they can be used only in areas where large explosions and associated phenomena can be tolerated. Stripping over-burden from copper or iron ore deposits may be a potential use. However, the use of nuclear explosives would require isolation, favorable topography, favorable ground-water conditions, and a low population density. If these basic requirements can be met, the use of nuclear explosives for overburden removal is considered to offer both economic and time advantages.

105 (UCRL-12248-T(Rev.1)) NUCLEAR EXCAVATION. A Progress Report. Nordyke, Milo D. (Lawrence Radiation Lab., Univ. of California, Livermore). Contract W-7405-eng-48. 5p. (CONF-660606-6). Dep. mn.

From American Nuclear Society Meeting, Denver.

A review is presented of developments in investigations of nuclear explosives applications in industry. Applications relating to excavation, mining, and isotope production are being investigated. Information is included on single-charge cratering, row-charge cratering, and costs of nuclear devices.

1. American Isthmian Sea-level Canal

Published Literature

106 METEOROLOGY IN STUDIES FOR A NEW ISTHMIAN CANAL. Reed, J. W. (Sandia Corp., Albuquerque, N. Mex.); Ferber, G. J. Bull. Amer. Meteorol. Soc., 48: 13-15(Jan. 1967). (SC-R-66-1012).

Feasibility studies are currently underway to indicate whether or not a sea level canal may be dug with nuclear explosives and at less cost than by conventional excavation methods. Safety problems must be understood before actual excavation may begin. The roles of atmospheric propagation of radioactivity and airblast must be considered in the planning for safe nuclear excavation. Meteorological studies must be conducted to show whether atmospheric conditions may impose uneconomical restrictions on nuclear device yields or excavation firing schedules.

107 NUCLEAR ELECTRICAL POWER FOR CANAL CONSTRUCTION. McDonald, G. Corry (Sandia Corp., Albuquerque, N. Mex.). Mech. Eng., 88: No. 8, 22-8(Aug. 1966).

The use of nuclear reactors to furnish a portion of the electrical power required for the construction of a sea-level Isthmian canal is described. Interactions of nuclear and electrical power with the mining processes are also described. Cost estimates for electric power from nuclear reactors and conventional fuels are presented. It was concluded that nuclear power reactors can be used economically to furnish a minor portion of the electrical power required for sea-level canal construction. At the present time it appears that only about 20 to 30 Mw of reactor-generated power of a total required load of 3000 to 4000 Mw may be economically furnished by nuclear reactors.

108 NUCLEAR PLAN. pp. 274-85 of Panama: Four Hundred Years of Dreams and Cruelty. Howarth, David. New York, McGraw-Hill Book Co., 1966.

The history of the Panama Canal Zone is discussed. The need for another canal across the Isthmus to handle large ships, e.g., aircraft carriers is described. Possible routes for the canal and the probable cost of each using nuclear excavation technology are presented. Two problems must be overcome before nuclear excavation is possible: The agreement of the signatories of the Nuclear Test Ban Treaty must be obtained and the people living in the area must be persuaded that the operation is safe.

109 TO BUILD A BIGGER DITCH. Miller, August C. Jr. U. S. Nav. Inst., Proc., 27-34(Sept. 1967).

The feasibility of using nuclear explosions to build a new sea-level canal in Central America or Colombia connecting the Atlantic and Pacific Oceans is discussed. This canal would eliminate traffic jams in world commerce that have built up on the present Panama Canal. The need for the new canal is discussed. Political, economic, and social aspects of the venture are described. Various routes for the new canal are discussed and the economic advantages of each compared. The advantages and disadvantages of using nuclear explosives to build the canal are outlined.

Reports

110 (CGS-P-117) INVESTIGATION AND INSTRUMENTATION OF PANAMA AND COLOMBIA STRONG-MOTION SEISMOGRAPHS. (Coast and Geodetic Survey, Las Vegas, Nev. Special Projects Party). Sept. 20, 1967. 84p. Dep.

Strong-motion seismograph stations installed for the Inter-Oceanic Canal project in Colombia at Bogota, Cali, Medellin, Cartagena, and Barranquilla; and two stations located in Panama City were inspected. Three additional strong-motion seismograph stations were installed in the Colombian cities of Monteria, Manizales and Medellin. A preliminary seismic investigation in Colombia of the July 29, 1967, earthquake was made.

111 (NVO-99-24) SEICHE AND TSUNAMI EFFECTS FROM NUCLEAR EXCAVATION OF AN INTEROCEANIC CANAL. (Blume (John A.) and Associates Research Div., San Francisco, Calif.). Feb. 1968. Contract AT(26-1)-99. 49p. Dep.

Includes Appendix by R. L. Wiegel.

Potential damage from water waves, including seiches and tsunamis which might be generated by proposed nuclear excavation in the Isthmus of Panama, is investigated. The history of the region shows a relative freedom from earthquake-generated waves. Predicted ground motion for the Panama Canal area will probably cause only negligible wave heights in the Canal. Nuclear excavation intersecting the shoreline may generate waves of damaging proportions. Additional studies are recommended.

112 (UCRL-50050-1) RELATIVE SIGNIFICANCE INDEX OF RADIONUCLIDES FOR CANAL STUDIES. James, Ralph A.; Fleming, Edward H. Jr. (California Univ., Livermore, Lawrence Radiation Lab.). Sept. 13, 1966. Contract W-7405-eng-48. 10p. Dep. mn.

A method is presented for arranging the radionuclides in the order of decreasing relative significance. In the current absence of sufficient data to do otherwise, it is assumed temporarily that the fraction, k, of each nuclide existing in the environment ingested per day is constant. The value of k for each nuclide that gives the maximum allowable dose suggested for the general public by the ICRP thus allows arranging the nuclides in the order of their significance. The relative significance index in terms of decreasing significance includes (in this order): $^{90}Sr - {}^{90}Y$, ^{210}Pb + chain, $^{137}Cs - {}^{137m}Ba$, $^{106}Ru - {}^{106}Rh$, ^{185}W, ^{181}W, ^{144}Ce, ^{54}Mn, ^{55}Fe, ^{45}Ca, ^{89}Sr, ^{91}Y, ^{147}Pm, ^{22}Na, $^{95}Zr - {}^{95m}Nb$, $^{103}Ru - {}^{103}Rh$, ^{59}Fe, ^{141}Ce, $^{125}Sb - {}^{125m}Te$, $^{129}Te - {}^{129m}Te$, ^{155}Cu, $^{131}I - {}^{131m}Xe$, $^{140}Ba - {}^{140}La$, ^{32}P, and ^{143}Pr.

B. PHENOMENOLOGY AND TECHNOLOGY

Published Literature

113 COMPUTER CALCULATIONS OF EXPLOSION-PRODUCED CRATERS. Cherry, J. T. (Univ. of California, Livermore). Int. J. Rock Mech. Mining Sci., 4: 1-22(Jan. 1967).

A technique is presented for calculating, from first principles, the mound and cavity growth that occur during nuclear and high-explosive cratering events. It features a standard, numerical approach to high-intensity, stress-wave propagation coupled with a unique model of material behavior in brittle failure. A preshot testing program is presented which obtains the necessary material properties from logging tests in the medium and from lab tests of selected rock samples. In situ properties to be determined by field logging are density and elastic velocity (compressional and shear velocity). Calculations are presented for Project Hardhat (5 kt, nuclear in granite), Project Scooter (0.45 kt, high-explosive in alluvium), Project Danny Boy (0.42 kt, nuclear in basalt), Project Sulky (0.09 kt, nuclear in basalt), and 3 parameter studies featuring rhyolite equations-of-state. The Danny Boy calculation confirmed spalling to be the predominant nuclear cratering mechanism in hard, dry rock. This observation permitted the construction of a free-fall, throw-out model which gave a reasonable estimate of crater radius and ejecta boundary.

114 CRATERS FROM SURFACE EXPLOSIONS AND SCALING LAWS. Vortman, L. J. (Sandia Corp., Albuquerque, N. Mex.). J. Geophys. Res., 73: 4621-36(July 15, 1968).

Scaling laws for craters from surface explosions are derived from the nuclear explosions and applicable chemical explosions to date. The data are insufficient for defining scaling more accurately than by a first-order power law. Nuclear and chemical explosions are consistent in indicating that of the crater radii scale as a power of energy larger than $\frac{1}{3}$. A possible explanation of the larger scaling is hypothesized.

115 EXCAVATION WITH NUCLEAR EXPLOSIVES. PROMISE AND PROBLEMS. Johnson, Gerald W. (Univ. of California, Livermore). Phys. Today, 38-44(Nov. 1963).

The use of nuclear explosions to provide a crater or ditch for engineering purposes is discussed. The sizes and characteristics of the craters formed were found to depend on the magnitude of the charge, the depth of placement, the nature of the medium, and the spacing between charges. Plowshare events used in these studies are discussed. Problems with radiation release and shock waves are considered.

116 POTENTIAL EFFECTS OF PROJECT CHARIOT ON LOCAL WATER SUPPLIES, NORTHWESTERN ALASKA. Piper, Arthur M. Geological Survey Professional Paper 539. Washington, D. C., Department of the Interior, 1966. 49p. GPO.

Project Chariot — once planned as a nuclear-excavation test in northwestern Alaska — presumably might introduce some radioactive nuclides into local water supplies. An order-of-magnitude appraisal of the expectable concentrations of such nuclides in streams and other water sources was developed. The appraisal is reported because it is unique in scope and because its results are applicable generally to preliminary evaluations of other proposals for nuclear excavation. Project Chariot would involve simultaneous detonation of one 200-kiloton and four 20-kiloton nuclear explosives, all emplaced below the land surface. Expectable vented radioactivity would be 1,500 megacuries due to mixed fission products, including 3,000 curies due to ^{90}Sr, 3,000 curies due to ^{137}Cs, and 100,000 curies due to ^{131}I. This radioactivity would be dispersed downwind as fallout; about 50 percent within a distance of 2 miles from ground zero, 75 percent within 10 miles, and 90 percent within 30 miles. The area receiving fallout (radioactivity more than 0.005 megacurie per square statute mile) would be some 1,500 square miles and would have a maximum downwind reach of about 125 miles. Subsequent redispersal of the fallout in and by water of the area is analyzed for four hypothetical cases, which together span the yearly range in hydrologic conditions. The four cases assume: (case I) detonation 30 days prior to breakup in the spring, ordinarily in April, fallout being on continuous snow cover; negligible redistribution of fallout by the wind; snowmelt runoff of 1 inch over the area, within 30 days following breakup; snowmelt detained in microponds (minute pools), 0.3 inch over the area; (case II) detonation at the close of melt-water runoff, ordinarily in early June; within the 30 days following detonation, a precipitation total of 0.5 inch but not more than 0.1 inch in any one storm; runoff averaging 0.03 inch but none generated by rain during the 30-day period; (case III) detonation in early August, following 2 months of minimum precipitation and an accumulated soil-water deficiency of 1 inch; within the 30 days following detonation, rainfall of 2.5 inches generating runoff of 0.7 inch; (case IV) detonation in late September, 10 days prior to freezeup, fallout being on saturated tundra; in the 10-day interim, no precipitation and 0.1 inch of runoff. Among the four hypothetical cases, the radioactivity interjected in streams owing to dissolved nuclides would be by far the least in case III, as detonation in early August would be followed by heavy rains. For the more distant parts of the fallout area this activity would be less than the lifelong drinking-water standard. Activity in the streams due to suspended fallout particles would be nearly zero in case II, as detonation ordinarily in early June would be followed by light rainfall and minimum runoff. Total stream burden would be greatest in case III, which encompasses an interval of high momentary streamflow but moderate average flow. Activity that does not reach the streams soon after detonation would of course remain in the area — adsorbed on land-surface materials, infiltrated to soil water or ground water, or dispersed over the land surface as insoluble particulate matter. In the aggregate, this remaining activity would include the greater part of that vented. Insoluble particles on the land surface would probably move to the streams over a period of years, ordinarily in concentrations progressively less with each passing year. For most of the area, the management problems should vanish within a few years.

Reports

117 (AD-626899) ENGINEERING PROPERTIES OF NUCLEAR CRATERS. REPORT 1. SITE SELECTION INVESTIGATIONS, WET MEDIUM CRATERING EXPERIMENTS. Saucier, R. T.; Banks, D. C. (Army Engineer Waterways Experiment Station, Vicksburg, Miss.). Oct. 1965. 85p. (TR-3-699).

Investigations were made to select a site suitable for producing craters in a saturated cohesive medium by small-scale high-energy detonations. According to prescribed criteria, the ideal site would be a large (200 acres or more), cleared, moderately flat tract of Federally owned land characterized by soft, homogeneous clays to a minimum depth of 40 feet. An evaluation of the U. S. by physical divisions revealed that suitable sites might occur in four general areas: the Lake Bonneville area; the Lake Agassiz area; the Great Lakes area; and the lower Mississippi Valley area. Acquisition and analyses of pertinent data on these areas indicated a need for field reconnaissances except in the case of the Great Lakes area which was eliminated from further consideration because of heterogeneous soil deposits. A reconnaissance of the Lake Bonneville area indicated the presence of apparently favorable test site conditions in a portion of the Dugway Proving Ground, Utah, while a reconnaissance of the Lake Agassiz area of North Dakota and Minnesota revealed generally unfavorable soil conditions. In regard to the lower Mississippi Valley area, three possible site areas were visited. Three borings were made at the Dugway Proving Ground site and two borings at the Brickeys (lower Mississippi Valley) site to investigate the depth

and homogeneity of the clay deposits. Natural water contents and unconfined compressive strengths were determined on selected undisturbed samples from both sites. Considering the soil conditions together with such factors as land ownership, proximity of cultural features, and probability of surface flooding, it was concluded that the Dugway Proving Ground site is more suitable for the project than any other site considered. (123 references.)

118 (NP-16699) ENGINEERING PROPERTIES OF NUCLEAR CRATERS. REPORT 5. RESIDUAL SHEAR STRENGTH OF WEAK SHALES. Herrmann, H. G.; Wolfskill, L. A. (Massachusetts Inst. of Tech., Cambridge. Dept. of Civil Engineering). Dec. 1966. Contract DA-22-079-civeng-66-3. 203p. (TR-3-699; R-66-57).

Laboratory studies of the residual shear strength of weak shales such as might be encountered in construction within the Canal Zone are described. This measurement is proposed as an index property to estimate the potential for shales or deeply weathered rocks to lose substantial strength with time. In addition to the residual strength parameter, five other index properties are outlined to form a comprehensive means for expediently evaluating potential loss of strength. The residual shear strength is a constant for any given soil regardless of stress history, and is the lowest "ultimate" strength. In practice, the laboratory measurements of residual strength can vary simply because of failure to reach this lowest strength. The main effort in this present research is to develop the equipment and testing procedures to reliably measure residual strength. It was found that the repeated direct shear test, with about 30 repetitions of loading, on mechanically disintegrated and resedimented samples resulted in an adequate index property test. The results of comprehensive testing of two Canal Zone shales (from the Cucaracha and the Culebra formations), Pierre shale from the Oahe damsite in South Dakota and a kaolinite clay are described.

119 (NVO-1229-87) HYDROLOGIC REDISTRIBUTION OF RADIONUCLIDES AROUND A NUCLEAR CRATER. Charnell, R. L.; Fenske, P. R.; Guinasso, N. L. Jr.; Schell, W. R.; Zorich, T. M. (Isotopes, Inc., Palo Alto Calif.). July 1967. Contract AT(29-2)-1229. 46p. Dep.

A conceptual model for redistribution of radionuclides around a nuclear excavated crater has been formulated. This model relies on many simplifications to allow analysis of the entire hydrologic system around the crater at the same time. The model is separated in terms of three major regions: fallout zone; ground water zone; and crater rubble zone. The redistribution within each of these sections is treated separately. The entire redistribution of radionuclides is obtained by combining effects from all three sections. The model in its present form is general. It can be applied to many nuclear cratering detonations. The model must be evaluated and refined in terms of a specific cratering application.

120 (PNE-5004P) CONSTRUCTION TECHNIQUES AND COSTS FOR UNDERGROUND EMPLACEMENT OF NUCLEAR EXPLOSIVES. Samuelson, W. J.; Hair, J. L. (Army Engineer District, Fort Worth, Tex.); Fisher, P. R. (Army Engineer Nuclear Cratering Group, Livermore, Calif.). Aug. 1965. 217p. Dep. mn.

Equipment, methods, and cost that are considered feasible for constructing underground emplacements for nuclear explosives such as would be used in nuclear excavation are described. Discussions are included concerning the available methods and techniques being used in big hole (36-in.-dia and larger) drilling, tunneling, and conventional shafting. The technical data were collected from the literature and by personal contacts with Government agencies and private industries. Big hole drilling methods can be divided into four types: churn drilling, auger drilling, calyx drilling, and rotary drilling. Of these, auger drilling is the most economical for holes to depths of 150 ft in soft material, and rotary drilling is by far the most popular choice for depths in excess of 150 ft. Rotary drilling is not limited to any specific material type and therefore is the most adaptable method. Equipment for rotary drilling is variable but in most cases consists of "beefed-up" oil well rigs employing modified hoisting facilities. Discussions concerning mining and shafting cover the conventional cyclic method of drilling and blasting as well as the mechanical mining methods. Mechanical tunneling methods are used with much success in both soft and hard rock. New equipment has become available with emphasis being placed on increasing the thrust capabilities of the cutter heads and improving the design of the cutters. Cost analyses for big hole drilling are included along with analyses for tunneling and shafting. These costs are believed realistic for the current period and are considered adequate for making preliminary cost estimates.

121 (PNE-5005) ENGINEERING–GEOLOGIC INVESTIGATIONS. Project DANNY BOY. Final Report. Nugent, R. C.; Banks, D. C. (Army Engineer Waterways Experiment Station, Vicksburg, Miss.). Aug. 1966. 104p. Dep. mn.

Preshot and postshot investigations of the Danny Boy site were made to obtain information on the change in engineering properties of the basalt media adjacent to the crater and to determine engineering properties of the important physiographic features of the crater such as ejecta and fallback materials. Field investigations included geological studies of the area and core borings in which borehole photographs were made and water pressure tests were conducted. Particle size distribution and density of the ejecta materials were determined. Rock media at the Danny Boy site consist of a moderately fractured basalt that caps a relatively thick sequence of soft tuffs and tuffaceous alluvium. The basalt cap varies from 204 to 229 ft in thickness and is composed of at least two separate flows. The upper flow, consisting of a vesicular zone overlying a nonvesicular zone, is relatively constant in overall thickness throughout the mesa, varying from 140 to 160 ft. The lower flow, averaging 68 ft in thickness, is more variable in lithologic composition, encompassing possibly two individual flow units. No borehole camera photographs were made of the preshot holes, and therefore little detailed information is known concerning the preshot structural conditions at the Danny Boy site. Laboratory tests indicated that the properties of the basalt vary widely, depending on the vesicularity of the basalt. The unconfined compressive strength generally increases as the density of the basalt increases. Postshot investigations indicated that the uplift of the ground surface at the crater perimeter varied from 8.5 to 20.2 ft, and averaged 14.5 ft. No indication of faulting or overturning was noted in trenches excavated through the ejecta. The average preshot joint spacing based on measurements of natural joints and postshot vertical borings varied between 1.25 and 1.6 ft. The blast-induced fractures developed in a subparallel or parallel fashion to the preshot joint system. The structure pattern at the site remained essentially unchanged after the blast, except for an increase in the total number of fractures present and a slight increase in the overall variability of the joint pattern. The natural joints tended to open up as a result of the blast. The Danny Boy crater was too small in relation to the characteristics of the material cratered to provide much insight into crater stability. All components of the slope are relatively stable, and slope readjustments, while probable, should be both slow and surficial.

122 (PNE-5009) ENGINEERING PROPERTIES OF NUCLEAR CRATERS. REPORT 4. THE FORMATION AND INITIAL STABILITY OF SLOPES ON COHESIONLESS MATERIALS. Technical Report No. 3-699. MacIver, Bruce N. (Army Engineer Waterways Experiment Station, Vicksburg, Miss.). Aug. 1967. 113p. Dep.

The engineering properties of nuclear craters were studied to identify and describe the physical properties that will control the use of a nuclear crater for engineering purposes. One of the prime considerations in the engineering use of a nuclear crater is the stability of the crater slopes. The inclination of a slope formed by deposition of cohesionless material is termed the angle of deposition. The angle of repose is defined as the maximum possible inclination of a slope of cohesionless material. Such factors as particle size, shape, and angularity, structure of particle aggregations, manner of deposition, and geometry of slopes are discussed with regard to their relative influence on each of the aforementioned angles. A few simple analytical relations are given to aid in understanding the behavior of particles during deposition and their stability on an inclined surface. Empirical data from laboratory tests, stockpiles, rock-fill dams, natural slopes, explosion-produced craters, etc., are presented and compared. It is concluded that angles of deposition for cohesionless rock and soil materials vary between 22 and 42 deg, and generally lie between 34 and 37 deg for angular particles, whereas angles of repose range between 27 and 47 deg, and generally lie between 37 and 47 deg for angular particles. The initial factor of safety of a slope formed by deposition will probably exceed 1.1 but will be no more than 1.5 in most cases.

123 (PNE-5010) ENGINEERING PROPERTIES OF NUCLEAR CRATERS. A STUDY OF SELECTED ROCK EXCAVATIONS AS RELATED TO LARGE NUCLEAR CRATERS. Kley, Ronald J. (Army Engineer Nuclear Cratering Group, Livermore, Calif.); Lutton, Richard J. (Army Engineer Waterways Experi-

ment Station, Vicksburg, Miss.). Sept. 8, 1967. 159p. Dep.

Analogies between nuclear and conventional excavations were developed from a tabulation of data from 153 mine, quarry, roadway, and dam excavations. The following factors were used as the basis for tabulation of conventional excavation data: purpose, location, precipitation, temperature, ground water level, lithology, mass strength, structural pattern, slope plan, slope profile, depth of excavation, slope height, average inclination, and stability. It was found that average slope inclination tends to be greatest for hard material and for material lacking a well-developed structure and that inclination tends to decrease with increasing slope height for excavated slopes reported to be stable. It is concluded that good analogies are to be found in shape, slope height, depth of excavation, and slope inclination. Loadings of waste material at the rim of some open pit mines may be analogous to ejecta on the lips of nuclear craters. Rubble zones found in some open pit mines may be analogous to the fallback zones of nuclear craters. Differences between preshot and postshot characteristics of cratered media must be appreciated in evaluating analogies between features of conventional excavations and preshot features of nuclear excavation sites. Brief descriptions of 21 selected excavations are presented in Appendix A. The results of this study serve as an aid to judgment of nuclear crater slope stability. Potential subjects for further study are identified.

124 (PNE-5012-1) ENGINEERING PROPERTIES OF CRATERS. DESCRIPTION OF CRATER ZONES AND SITE INVESTIGATION METHODS. Report I. Fisher, Paul R. (Army Engineer Nuclear Cratering Group, Livermore, Calif.). Feb. 20, 1968. 78p. Dep.

The current state of knowledge concerning the physical character of the distinct zones of disturbance surrounding a nuclear or high explosive crater, the scope and techniques of engineering properties investigations at the sites of cratering experiments, and methods for predicting the character of crater zones from the results of predetonation investigations are discussed. Information is based on data obtained from craters produced in dry materials. The distinct zones of disturbance observed at nuclear and high explosive craters are the fallback zone, the ejecta zone, and the rupture zone (which includes the zone of upthrust). Characteristics for craters in dry materials may be predicted with reasonable accuracy.

125 (SC-DC-67-2330) PHOTOGRAMMETRIC TECHNIQUES ASSOCIATED WITH MODEL STUDIES OF EARTH-MOVING EXPLOSIONS. Love, George C.; Vortman, Luke J. (Sandia Corp., Albuquerque, N. Mex.). Nov. 1967. Contract AT(29-1)-789. 38p. (CONF-680203-1) Dep.

From American Society of Civil Engineers Transportation Conference, San Diego, Calif.

The possible future use of nuclear explosives for large-scale excavation projects has led to small-scale investigation of cratering and ejecta mechanisms using chemical explosive charges. Photogrammetric techniques have been developed which enable rapid accurate measurement of crater dimensions. Ground-supported stereo photography is utilized before and after explosions for mapping with contour lines at 0.2-foot intervals and spot elevations at 0.1-foot accuracy. A similar technique with a horizontal line of sight is used to locate in three dimensions gages which measure geometry and strength of the blast wave as it vents from the ground. Information obtained from these experiments will guide further testing and be instrumental in determining placement and charge sizes for nuclear explosive earth moving. Other applications of these photogrammetric techniques are possible.

126 (SC-RR-67-616) MAXIMUM MISSILE RANGES FROM SURFACE AND BURIED EXPLOSIONS. Vortman, L. J. (Sandia Corp., Albuquerque, N. Mex.). Sept. 1967. 17p. Dep.

The ballistic boundaries, or maximum ranges of ejected material, for many applicable surface and buried explosions are summarized and scaling expressions are derived which will be helpful in predicting the ballistic boundaries for explosions of other energies. In establishing safety zones it is advisable to multiply predicted boundaries by a factor of 1.5 to 2.0, because of a finite probability that the boundaries observed for a limited number of events will be exceeded if more shots are fired.

127 (UCRL-12172) NUCLEAR CRATERING EXPERIENCE AT THE PACIFIC PROVING GROUNDS. Circeo, Louis J. Jr.; Nordyke, Milo D. (Lawrence Radiation Lab., Univ. of California, Livermore). Nov. 10, 1964. Contract W-7405-eng-48. 92p. Dep. mn.

A report is presented on a study conducted to observe the long-term effects of weathering on 10 nuclear craters over periods as long as 12 years. The study consisted of an investigation and resurvey of selected craters on Bikini and Eniwetok Atolls, including documentary photography; hydrographic, topographic, and geologic data; and general engineering observations. These data were compared with information collected from previous pertinent reports and studies. A summary of all the data from previous and present studies is included. Cratering curves for these surface detonations are developed, based primarily on the empirical data. Crater radius is shown to scale as $W^{\frac{1}{4}.5}$, similarly to the observed scaling dependence of other fireball phenomena. Crater depth after water washing was shown to scale as $W^{\frac{1}{4}}$. The effect of low heights of burst appears to be relatively minor in determining crater dimensions. Changes in crater topography are noted and investigated. The alteration of shoreline processes as a result of nuclear craters is discussed. The comparison of craters formed by surface and subsurface detonations and subsequent phenomena is considered.

128 (UCRL-14171) PRINCIPLES OF NUCLEAR EXCAVATION. Nordyke, Milo D. (Lawrence Radiation Lab., Univ. of California, Livermore). May 25, 1965. Contract W-7405-eng-48. 31p. Dep. mn.

Basic cratering concepts and the present state of nuclear excavation technology are described. The general nature of the safety hazards associated with nuclear excavation are also discussed, and specific applications of nuclear excavation techniques to a large-scale construction project are briefly outlined. It was concluded that nuclear explosions are capable of making craters that are suitable for many large-scale construction projects and that, with appropriate safeguards and studies, they can be used safely. Nuclear excavation costs in hard rock are estimated to be competitive with conventional excavation in 10-kt range, rapidly decreasing to a few cents per cubic yard in the megaton range.

129 (UCRL-14191(Rev.1)) ARTIFICIAL AND NATURAL RADIOACTIVITY IN NUCLEAR EXCAVATION. Higgins, Gary H. (Lawrence Radiation Lab., Univ. of California, Livermore). June 2, 1965. Contract W-7405-eng-48. 19p. Dep. mn.

Nuclear excavation technology is briefly reviewed. Areas discussed are scaling laws, canal excavation, costs, and safety. The radioactivity resulting from nuclear excavation of a sea-level Isthmian canal is estimated and compared with natural background radiation.

130 (UCRL-14778) RELEASE OF RADIOACTIVITY FROM NUCLEAR CRATERING EXPERIMENTS. Miskel, John A. (Lawrence Radiation Lab., Univ. of California, Livermore). Aug. 26, 1966. Contract W-7405-eng-48. 12p. (CONF-660920-6). Dep. mn.

From 1st International Congress of the International Radiation Protection Assn., Rome, Italy.

The use of nuclear explosives for excavation purposes results in the release of radioactivity to the atmosphere. The fraction of the total amount of a given species produced and released to the atmosphere depends on the chemical properties of the species and on the nature of the cratering process. Data obtained from several nuclear cratering experiments indicate that the fractions of the more volatile species released are relatively insensitive to the cratering phenomenology, whereas the fraction of the refractory species released are highly dependent on it. The controlling factor for the refractory species appears to be the filtering action of the earthmound raised in the initial stages of the crater formation. Two different cratering processes have been studied experimentally. In one, an erosional crater was formed which resulted in essentially no filtering of the debris during the release; in the other, two craters were formed, one with "normal" filtering and one with a much thicker filter bed than optimum. The results of these experiments are presented to document the effect of the filter action on the various radionuclides. The hazard evaluation for engineering programs involving nuclear excavations can be divided into two parts: first, the close-in area which is of interest with respect to the time-delay of further work on the engineering project; and second, the long-range distribution of the radioactive materials with respect to the entry of radiation into the outside world. Data from the excavation experiments to date indicate that the close-in fallout is dependent primarily on the chemical species involved; the long-range concentrations appear to be independent of the detailed nature of the source, but depends primarily on the atmospheric dissipative processes once the early fallout has occurred.

131 (UCRL-50409) OBSERVED FRACTIONATION IN GROUND LEVEL FALLOUT FROM THREE NUCLEAR CRATERING DETONATIONS. Gibson, Thomas A. Jr. (California Univ., Livermore. Lawrence Radiation Lab.). Apr. 4, 1968. 7p. Dep.

Data relating to radionuclide deposition (fallout) within a few miles of the Danny Boy, Sedan, and Palanquin nuclear cratering shots were examined for evidence of fractionation, i.e., differences in relative proportions of fission products in debris samples as compared with the relative proportions originally formed. A fractionation index is computed for several fission-product mass chains produced in each event. This index is particularly useful because it is independent of the total yield and fission yield of the detonation and also of the total amount of radioactive material deposited in the early fallout pattern. By comparing these indices with one another, one can determine whether fractionation occurred and obtain a quantitative estimate of its degree. For the three events studied here, only Danny Boy showed unambiguous evidence of fractionation in the early fallout, and the degree of fractionation was small. In Danny Boy there was only a factor of four difference between most enriched and most depleted species, as compared with the factors of several hundred that have been observed in many late time samples of airborne debris. If this small amount of fractionation proves to be true in general for cratering shots, then predictions of early-fallout gamma radiation patterns will be greatly simplified.

C. HIGH EXPLOSIVE EXPERIMENTS

Reports

132 (PNE-507) PROJECT PRE-SCHOONER II. Technical Director's Summary Report. Final Report. (Army Engineer Nuclear Cratering Group, Livermore, Calif.). Dec. 1965. 129p. Dep. mn.

Project Pre-Schooner II was a chemical explosive single-charge cratering experiment conducted as a correlation detonation for the proposed Plowshare 100-kt Schooner nuclear cratering experiment. The primary purpose of this experiment was to improve the knowledge of cratering in a hard, dry rock and to provide information which can be used in the emplacement design of the Schooner event and in the assessment of the operational safety aspects of that event. Pre-Schooner II consisted of a 100-ton liquid explosive nitromethane charge emplaced in a spherical cavity at a depth of 71 ft in the rhyolitic rock formation of the Bruneau Canyon region in southwestern Idaho. As a result of a leak which developed in the cavity, there were only 85.5 tons of nitromethane in the cavity at detonation time with an energy equivalent yield of 94.6 tons. The crater produced by the detonation had an apparent crater radius of 95.2 ft and an apparent crater depth of 60.7 ft. The apparent crater volume was 24,780 yd^3, and the average lip crest height was 17.2 ft. The maximum range of missiles was 2320 ft. Results of surface motion studies indicate that a peak spall velocity of 129 ft/sec occurred at GZ at 27 msec after zero time. Results of the subsurface measurements program indicate that: the signal time of arrival measurements and peak stress measurements in the horizontal direction from the shot point were in close agreement with the SOC computer calculation predictions; the signal time of arrival and peak stress measurements in the vertical direction evidenced considerable scatter and were generally lower (for stress measurements) or occurred at a later time (for time of arrival measurements) than was predicted by the SOC calculation; a peak positive vertical acceleration of 3000 g was measured by the accelerometer located near the upper surface of the rhyolite medium approximately 10 ft below the surface of the ground; and the cavity pressure measurements, recorded over the time period that the fluid column functioned properly, agreed quite well with predicted measurements. Strong motion measurements recorded at two stations, located 2.4 and 4.7 km east of GZ, produced acceleration data which agree quite well with predictions. The observed displacements at these two stations and the velocities recorded at four other stations located east and north of GZ were higher than predicted. Maximum observed cloud dimensions were: crosswind base surge radius, 2100 ft; base surge height, 1060 ft; main cloud radius, 875 ft; and main cloud height, 1400 ft. Preliminary analysis of the close-in air blast measurements indicates that the ground-shock-induced pressures were twice those from previous cratering detonations at comparable scaled ranges. Analysis of the microbarograph measurements show that the average long-range air blast transmission factor was 0.19. Observations, results, and conclusions are preliminary and subject to change based upon detailed analyses and interpretation of data.

133 (PNE-509) PRESHOT GEOLOGIC AND ENGINEERING PROPERTIES INVESTIGATIONS: PROJECT PRE-SCHOONER II. Lutton, Richard J.; Girucky, Frank E.; Hunt, Richard W.; Curro, Joseph R. Jr. (Army Engineering Waterways Experiment Station, Vicksburg, Miss.). Oct. 1967. 112p. Dep.

The Pre-Schooner II site was selected, from five areas investigated, on the basis of refraction seismic surveying, core drilling, and surface mapping in extrusive igneous rock that generally models the nearby Schooner site. Bedrock below about 5 feet of stony silt consists of a 25-foot-thick layer of vitrophyre and vitrophyre breccia over felsite that extends to a depth of at least 150 feet. These two bedrock layers at the site have distinctly different physical properties, the felsite being relatively less porous and stronger in compression than the overlying vitrophyre. The felsite is massive at depth, although highly fractured, but it becomes steeply flow-layered in the upper portion. The flow layers continue across a gradational zone into the overlying vitrophyre. The resultant structure strikes about north 35 degrees east. The felsite is conspicuously jointed, and the vitrophyre contains abundant microscopic cracks.

134 (PNE-511) CLOUD DEVELOPMENT STUDIES. Project PRE-SCHOONER II. Day, Walter C. (Army Engineer Nuclear Cratering Group, Livermore, Calif.); Rohrer, Robert (Lawrence Radiation Lab., Univ. of California, Livermore). Feb. 1966. Contract W-7405-eng-48. 29p. Dep. mn.

Cloud development data are presented for the Pre-Schooner II high explosive cratering event conducted in a rhyolite medium in southwestern Idaho. Early base surge radius dimensions are given as a function of time in several directions, and are related to base surge cloud dimensions from past cratering experiments in alluvium and basalt. Measurements of base surge height, main cloud radius, and main cloud height are also given. Two new methods of cloud delineation are described: (1) a laser-radar technique, and (2) a fluorescent particle tracer technique.

135 (PNE-512-F) AIR-BLAST MEASUREMENTS. Project PRE-SCHOONER II. Reed, Jack W.; Vortman, Luke J. (Sandia Corp., Albuquerque, N. Mex.). Sept. 1967. 60p. Dep.

Air blast resulting from detonation of 85.5 tons of nitromethane buried 71 feet in rhyolite rock was measured close-in, both along the ground and in a vertical field above the explosion, and also at long distances from the explosion. Close-in air-blast wave forms consisted of two positive pulses, the first induced by the ground shock and the second, larger, pulse from venting gas. Measured ground-shock-induced peak overpressures were larger than anticipated. Peak over-pressures from venting gas likewise were larger—so much so that the system was over-ranged, resulting in loss of many of those peaks and degrading the results. A tentative overpressure and energy distribution in the field above the explosion was derived. Air-blast transmission to a large distance was about the same as experienced on other large HE explosions at comparable burial depths. Since the state of the art of neither close-in air blast nor large-range propagation was advanced appreciably, no significant conclusions are presented.

136 (PNE-514) PROJECT PRE-SCHOONER II: GROUND SHOCK MEASUREMENTS. Final Report. Davis, Lawrence L. (Beers (Ronald F.), Inc., Alexandria, Va.). Apr. 1966. Contract AT(29-2)-1163. 61p. Dep.

An instrumentation plan was designed for the purpose of collecting seismic data which would be useful for making future predictions for the Schooner event. Peak ground motions were predicted at each station so that instruments could be set at the proper recording levels. Good data were obtained at each station. The velocity data from six stations which employed tape recording were processed to remove the frequency dependency of the instrument response, and acceleration and displacement were derived from the corrected velocity recordings. Additionally, the velocity recordings were subjected to band-pass filtering and amplitude-frequency relations were obtained. The observed peak values of ground motion are presented in tabular and graphical form. Where appropriate, least-squares regression equations were fitted to the observed data. Comparisons of the observed data with the predictions show that in all but one case the predictions were low. The frequencies associated with the largest velocity amplitudes ranged from about 2 to 9 cps.

137 (PNE-515) SUBSURFACE EFFECTS MEASUREMENTS. Project PRE-SCHOONER II. Final Report. Heusinkveld, Myron; Marks, Robert (Lawrence Radiation Lab., Univ. of California, Livermore). Jan. 1966. Contract W-7405-eng-48. 41p. Dep. mn.

Subsurface effects measurements were made on the Pre-Schooner

II event, which was an 85-ton nitromethane cratering experiment in southern Idaho. Measurements attempted included subsurface stress, time of arrival of the stress wave, acceleration, subsurface spall phenomena, gas pressure in the expanding detonation cavity, and vertical subsurface motion. The measured subsurface stresses were of essentially the same scaled amplitude as earlier results from Sulky and Palanquin, but were considerably lower than results from Hardhat and Shoal. Measured accelerations were higher in scaled amplitude than the results from Danny Boy, but were lower than the results from Hardhat. A subsurface spall was observed 8 meters below the surface 18 msec after detonation time. Early cavity pressure measurements were obtained, but the instrumentation failed before the time of greatest interest. The vertical subsurface motion experiment was unsuccessful.

138 (PNE-516) POSTSHOT GEOLOGIC AND ENGINEERING PROPERTIES INVESTIGATIONS. Project PRE-SCHOONER II. Frandsen, Alton D. (Army Engineer Nuclear Cratering Group, Livermore, Calif.). Sept. 1967. Contract W-7405-eng-48. 68p. Dep.

The Pre-Schooner II Event was a chemical explosive single-charge cratering experiment in hard, dry rock. The detonation was centered 71 ft below the ground surface and consisted of approximately 85.5 tons of nitromethane. The explosion produced a crater with an apparent radius of 95.2 ft and an apparent crater depth of 60.7 ft. Postshot explorations of the crater consisted of excavating three radial trenches through the lip material and then extending two of the trenches into the fallback within the crater. Both bulk densities and block-size distribution of the ejecta and fallback were obtained. Bulk densities averaged 103.8 pcf except for an anomolous value of 93.1 pcf in one trench. Block sizes varied from fines of clay size to blocks greater than 6 ft in diameter. The true crater radius and the lip upthrust were measured at the three trenches and averaged 100 ft and 11 ft, respectively. The crater slope angles measured before, during, and after completion of the fallback excavation averaged 37, 42, and 38 degrees, respectively.

139 (PNE-602F) GEOLOGIC AND ENGINEERING PROPERTIES INVESTIGATIONS. Project DUGOUT. Lutton, R. J. (Army Engineer Waterways Experiment Station, Vicksburg, Miss.). Dec. 1967. 188p. Dep.

The Dugout event was a row cratering experiment in which five 20-ton nitromethane charges spaced 45 feet apart at depths of 59 feet in dry basalt were detonated simultaneously. The explosion produced an apparent crater about 135 feet wide, 285 feet long, and 35 feet deep. Preshot and postshot NX core and calyx hole drilling, trenching, laboratory analysis of core samples, and analysis of photographs have revealed preshot structure, the extent and characteristics of the ejecta and fallback, the zone of blast fracturing, the zone of bulking, and a sheared zone. As revealed by preshot drilling, the upper basalt layer consists of about 40 feet of vesicular basalt overlying, with a gradational contact, about 50 feet of dense basalt. The vesicular basalt has been subdivided into four types on the basis of vesicle content and fabric. From 2 to 14 feet of silt overlies the bedrock. Unconfined compressive strength for 6 samples ranges from about 7,000 to 17,000 psi. Samples of dense basalt tested triaxially show a greater increase of strength with confining pressure than does a sample of vesicular basalt. Dynamic laboratory tests gave a compression wave velocity of 16,000 ft/sec for dense basalt and about 13,000 ft/sec for slightly vesicular basalt, and they indicated that Poisson's ratio averages about 0.25. Field seismic and vibratory studies indicate compression and shear wave velocities of about 1,000 and 700 ft/sec, respectively, in the surface soil and 4,000 and 1,300 ft/sec, respectively, in highly vesicular basalt. Flow layers complicating the otherwise simple stratigraphy form a system of nested cylinders with a mutal axis that parallels the direction of flow of the lava while it was still partly molten. Natural and blast-induced fractures have a preferred orientation parallel to flow layers. A second preferred orientation of joints is perpendicular to flow layers, but one major set of this group oriented normal to the cylinder axis is believed to be the dominant structural element modifying the crater process. A more or less continuous blanket of ejecta extends as far as 500 feet (in one direction) laterally from the preshot position of the line of charges. This granular material has a bulking factor of about 1.39. In the subsurface, the zone of in situ bulking and the zone of blast fracturing extend laterally as far as 250 feet, but in detail there appears to be a concentration of fracturing at a depth of about 60 feet. A zone of shear deformation extends at least as far laterally from the row charge as 100 feet. In each of these three subsurface zones the intensity of deformation decreases outward. The zone of blast fracturing along the projection of the row charge extends only about 160 feet from the end charge position, and the zone of shear deformation extends about 140 feet. A fourth zone characterized by relative displacement of points toward the crater with respect to points below is evident along the lip at the west end of the crater.

140 (PNE-603F) SURFACE MOTION MEASUREMENTS. Project DUGOUT. Terhune, R. W. (Lawrence Radiation Lab., Univ. of California, Livermore). Dec. 1965. Contract W-7405-eng-48. 116p. Dep. mn.

Accelerometers and high-speed motion picture photography were used to measure the motion of the surface as it was thrown up by Dugout—a chemical row-charge cratering experiment in basalt, in which five 20-ton charges spaced 45 feet apart and at a depth of 59 feet were fired simultaneously. The experimental procedure for the surface motion measurements and the results obtained are described. Velocity profiles at various points on the rising "mound" of upthrown material from Dugout are presented and compared with those from another cratering experiment, Pre-Schooner Alpha, in which a single 20-ton chemical charge (equivalent to one of the five Dugout charges) was fired in the same basalt material as Dugout and at the same depth.

141 (PNE-607F) MULTIPLE ROW CHARGE BLAST-WAVE OBSERVATIONS AT LONG RANGE. Final Report. Project DUGOUT. Reed, Jack W. (Sandia Corp., Albuquerque, N. Mex.). Mar. 1966. Contract AT(29-1)-789. 28p. Dep. mn.

Air-blast wave measurements were made at ranges from 4 km to 200 km from the Plowshare Dugout high-explosives cratering event at the Nevada Test Site. In the Dugout event, a row of five nitromethane spheres were arranged to create a maximum ditch. Thirteen microbarograph stations were operated to determine how much attenuation of the blast wave was caused by explosives burial. Results showed that distant wave amplitudes ranged from 0.11 to 0.49 times as large as would have propagated from one of the nitromethane spheres burst in free air. Rocket wind observations were made to allow sound-ray propagation calculations for comparison with observations. In general, propagations were stronger than this calculation predicted. Three smaller explosives were burst above ground and one was burst on the ground to check atmospheric propagation conditions and to calibrate Dugout waves. Records from identical aboveground bursts, fired in a 5-minute period, showed that blast amplitudes were repeatable only within a factor of 0.70 to 1.43.

142 (PNE-1101) SITE-SELECTION INVESTIGATIONS. PROJECT PRE-GONDOLA. Jack, H. A. (Army Engineer District, Omaha, Nebr.); Dudley, W. W. (Army Engineer Nuclear Cratering Group, Livermore, Calif.). Feb. 1967. Contract W-7405-eng-48. 45p. Dep. mn.

Site selection investigations are described for Project Pre-Gondola, a U. S. Army Engineer Nuclear Cratering Group chemical explosive cratering experiment in weak, saturated shale. The investigation was begun in January 1966 and concluded in June 1966 with the selection of an area adjacent to the Fort Peck Reservoir in northeastern Montana. In addition to an office study covering the U. S. and field reconnaissance of 14 sites, subsurface investigations with accompanying laboratory tests were conducted at the primary site and one alternate site near Edgemont, South Dakota. A second alternate site was considered at Cedar Ridge in Crook County, Wyoming, but no subsurface investigations have been conducted. The medium present at the Fort Peck site is the Bearpaw shale, a highly compacted, uncemented clay-shale of Cretaceous age. The laboratory unconfined compressive strength of the intact shale is as great as 500 psi, but the in situ field strength is reduced by bentonite seams and an extensive system of jointing and slumping. The medium is saturated, but its permeability is so low that free water is available to observation wells only where the shale is highly jointed. The site provides a variety of terrain conditions which make it suitable for all phases of the experiment, including a row crater in varying terrain.

143 (PNE-1104) CLOSE-IN GROUND MOTION, EARTH STRESS, AND PORE PRESSURE MEASUREMENTS. Project Pre-Gondola I: Cratering Site Calibration Series. Day, J. D.; Murrell, D. W.; Sherman, W. C. (Army Engineer Waterways Experiment Station, Vicksburg, Miss.). July 1967. 129p. Dep.

The objectives of this project were to measure and analyze the particle velocities, soil stresses, and pore water pressures produced by detonation of 20 tons of nitromethane in saturated clay-shale. The ground range of primary interest was 85 to 375

feet from surface ground zero with most instruments placed at shot depth (46.3 feet). Peak stresses were greater than estimated at the close-in locations (8,000 to 12,000 psi measured vs 5,000 psi predicted) and attenuated as the −2 power with distance. Particle velocities were consistently higher than predictions based on experienced in other media. High amplitude transient pore pressures were produced by the explosion. Residual excess pore water pressures tended to drop off slowly with time.

144 (PNE-1105) INTERMEDIATE RANGE GROUND MOTIONS. Project PRE-GONDOLA I. Power, Dean V. (California Univ., Livermore, Lawrence Radiation Lab.). May 22, 1967. Contract W-7405-eng-48. 52p. Dep.

Ground motions were measured during the Pre-Gondola site calibration events and the Pre-Gondola I events on Fort Peck Dam and free-field locations out to 95 km. These events included yields of 0.5 and 20 tons of high explosive detonated at various depths. A variation of peak ground motion with depth of burial was noted which indicated that peak motions from a completely contained explosion may be 1.5 to 2 times the motion resulting from an explosion placed at optimum depth for a cratering experiment. Attenuation with radius was found to be proportional to $R^{-2.45}$ for this region with at least one anomalous "hot spot" at 95 km north of ground zero (GZ). Motions on the dam were comparable to free-field motions but vibrations persisted for longer times at the dam's natural frequency. Variation in motion was found to be proportional to the 1.0 power of the yield. Predictions for motions resulting from the Pre-Gondola II event are made.

145 (PNE-1106) STRUCTURES INSTRUMENTATION. Project Pre-GONDOLA I. Ballard, Robert F. Jr. (Army Engineer Waterways Experiment Station, Vicksburg, Miss.). May 1967. 72p. Dep.

Three microseismic stations were operated by the U. S. Army Engineer Waterways Experiment Station (WES) during the Pre-GONDOLA I cratering calibration series at Fort Peck, Montana. The seismic stations, located in the center of the dam, the Gate Control Structure No. 3, and on the spillway, were monitored for the purpose of determining structure response resulting from the 20-ton charges detonated approximately 12 miles from the dam. Particle velocity data were recorded simultaneously on oscillographs and magnetic tape. Oscillograms were analyzed for maximum transient zero to peak particle velocities, and the tape was subjected to linear and power spectral density analysis from 0.5 to 20 Hz over a period of 160 sec. The results of the study indicate that the amplitudes recorded during this test series exceeded the motions recorded during the 1000-lb calibration series by approximately 30 times at all stations. This report presents a documentation of test data.

146 (PNE-1107(Pt.1)) CRATER STUDIES: CRATER MEASUREMENTS. Project PRE-GONDOLA I. Final Report. Harlan, Ronald W. (Army Engineer Nuclear Cratering Group, Livermore, Calif.). May 1967. 93p. Dep.

Project Pre-Gondola I, a series of four 20-ton high explosive cratering detonations, was conducted by the U. S. Army Engineer Nuclear Cratering Group during October and November 1966 in order to determine the cratering characteristics of the Pre-Gondola project site located about 18 miles south of the town of Glasgow, Valley County, Montana. The essentially flat site medium consisted of uncemented, highly compacted, moderately jointed shale of the Late Cretaceous age, Bearpaw shale formation. The craters produced were both deeper and wider than those previously observed in either alluvium or basalt, but had flatter slopes. For single-charge craters in Bearpaw shale the optimum depth of burst for both apparent crater depth and radius is about 130 ft/$kt^{3.4}$. Pertinent data for the four events are given.

147 (PNE-1108) CLOUD DEVELOPMENT STUDIES. Project Pre-Gondola I. Final Report. Day, Walter C. (Army Engineer Nuclear Cratering Group, Livermore, Calif.); Rohrer, Robert F. (California Univ., Livermore. Lawrence Radiation Lab.). July 1967. Contract W-7405-eng-48. 78p. Dep.

The clouds resulting from four 20-ton nitromethane cratering explosions in a wet clay shale medium were studied by photographic analysis and lidar (laser-radar) tracking. A technique for detecting tracers in future events in the same medium was investigated. It was found that the clouds were unique in that they were very diffuse (low particle density) and ceased to be visible within several minutes, there were no main clouds resulting from dynamic venting during mound rise, and steam was visible in the base surge clouds. Base surge radius dimensions observed were larger than those observed in basalt and smaller than those observed in alluvium. Base surge height dimensions were much larger than those previously observed in any medium due to the steam present in the cloud. Lidar tracking was successful and indicated its capability to provide information as a function of time on the position, motion, growth, and internal structure of cratering explosion clouds. Cloud sampling indicated that several elements including palladium, cadmium, indium, and europium are suitable for use as tracers in future chemical explosive cratering events at the Pre-Gondola I site.

148 (PNE-1110) LIDAR OBSERVATIONS OF THE PRE-GONDOLA I CLOUDS. Final Report. Oblanas, J. W.; Collis, Ronald T. H. (Stanford Research Inst., Menlo Park, Calif.). Jan. 1967. Contract AT(04-3)-115. 74p. Dep.

For Univ. of California Lawrence Radiation Lab., Livermore.

Lidar (laser radar) observations of the dust and steam clouds that resulted from the Pre-Gondola I series of four chemical explosions made near Fort Peck Reservoir, Montana, during October to November 1966 are described. The neodymium lidar was well able to track the clouds even when they became too tenuous to be seen visually or photographed. Observational data were analyzed to obtain cloud dimension, height, volume, rate of growth, volume backscatter coefficient and relative density variations. It is concluded that lidar tracking techniques can provide unique information on the position, motion, rate of growth, and internal structure of visible and sub-visible clouds resulting from large-scale explosions, and recommendations are made for improving the operational efficiency of the technique.

149 (PNE-1111) PRESHOT GEOPHYSICAL MEASUREMENTS. Project PRE-GONDOLA I. Stearns, R. T.; Rambo, J. T. (California Univ., Mercury, Nev. Lawrence Radiation Lab.). Apr. 11, 1967. Contract W-7405-eng-48. 58p. Dep.

A series of preshot downhole geophysical measurements was performed at three out of the four locations on the Pre-Gondola I site near Glasgow, Montana. These in situ measurements in nearly homogeneous shale included density, gamma ray−neutron, caliper, electric, three-dimensional velocity, continuous velocity and seismic uphole-downhole logging. All measurements except gamma ray−neutron and electric logging appear to have yielded useful quantitative data. Average densities ranged from 2.11 to 2.42 g/cm^3, and average velocities fluctuated between 1732 and 2014 m/sec below the weathered zone. Density measurements performed by the U. S. Army Engineer, Omaha District, compared favorably with those made by LRL. An opportunity to compare in situ sonic velocities made by three different tools in the same hole showed a variation in measured value with the method used. These data suggest that the distance between wave source and detector is responsible for the variation in measured velocity.

150 (PNE-1115) INTERMEDIATE RANGE GROUND MOTIONS FOR PRE-GONDOLA II AND ASSOCIATED EVENTS. Power, Dean V. (California Univ., Livermore. Lawrence Radiation Lab.). Apr. 1968. 76p. (UCRL-50433). Dep.

Ground motion records from seven high explosive cratering events in northeastern Montana were analyzed for peak velocity, power spectral density, and velocity spectra. The events included four 20-ton single charges at depths of burst which varied from 42 to 57 ft, a 140-ton row charge consisting of three 20-ton charges and two 40-ton charges at optimum depths of burst, and a fully coupled charge of 0.5 tons and a decoupled charge of 0.5 tons at optimum depths of burst. It was found that at these depths and charge weights an increase in depth of burst resulted in an increase in peak velocities and power spectral densities as measured at distinct points (>5 km), while no significant frequency shifts were noted. Power spectral density was found to be approximately proportional to the first power of yield. For this reason it was determined that power spectral densities varied inversely as radius to the 3.55 power, and peak velocities varied inversely as radius to the 1.6 power. An increase in both velocities and power spectral densities for small decoupling factors was found to occur for a certain explosive-cavity configuration. Three analysis techniques, peak velocity, velocity spectra, and power spectral density, are compared and it is shown that power spectral density is the most consistent method when comparing records from different measuring stations.

151 (PNE-1119) AIRBORNE LIDAR OBSERVATIONS. Project Pre-GONDOLA II. Final Report. Collis, R. T. H.; Oblanas, John (Stanford Research Inst., Menlo Park, Calif.). Nov. 1967. 60p. Dep.

Lidar (laser radar) observations from an aircraft of the cloud

of debris resulting from the Pre-GONDOLA II explosion at Fort Peck, Montana, are described. With the neodymium (near infrared) lidar pointing horizontally at 45° aft of the aircraft beam, the aircraft made a series of flights past the cloud position at a height of approximately 225 meters above ground level and the lidar was fired at intervals of approximately 6 seconds. Since the cloud rapidly became invisible, these flights were positioned with reference to the lidar observations using a Doppler navigation system. From the lidar observations the location, shape, and internal structure (in terms of variations of density) of the cloud at the flight level were determined at five successive times, extending some 37 minutes after the explosion and some 17 kilometers downwind. While this technique is thus shown to be immediately available (with minor improvements) for limited operational application, the developments necessary to realize its full potential are identified and described. In particular, significant improvements in the data handling system are proposed.

152 (PNE-5011) THE FORMATION OF A CRATER AS OBSERVED IN A SERIES OF LABORATORY-SCALE CRATERING EXPERIMENTS. Bening, Robert G.; Kurtz, Maurice K. Jr. (Army Engineer Nuclear Cratering Group, Livermore, Calif.). Sept. 1967. 63p. Dep.

A qualitative description of the formation of a crater is developed on the basis of a series of laboratory-scale cratering experiments. The results of 41 one-pound, single-charge cratering detonations in a concrete sand placed under controlled conditions are summarized. The effect of depth of burst on crater dimensions is illustrated. The crater formed by a one-pound charge buried at a depth of burst of 2 feet is selected for analysis because the ratio depth of burst to depth of apparent crater is similar to that considered desirable for a prototype nuclear excavation. On the basis of these experiments and a series of gram-size, half-space cratering experiments conducted behind a Plexiglas plate, a description of the formation of a crater is hypothesized. Subsidence or slumping of the cavity walls during the formation of the crater is shown to play an important part in the formational process. The importance of this mechanism to the analysis of crater stability is discussed.

153 (SC-RR-64-1703) AIR VENT: SURFACE MOTION PHOTOGRAPHY. Vortman, L. J. (Sandia Corp., Albuquerque, N. Mex.). Mar. 1965. 59p. Dep.

Results of surface motion displacement-time, velocity-time, and acceleration-time obtained from motion picture photography are presented for one 20-ton shot at a 17.1-foot burial depth and for 256-pound shots at burial depths from just below the surface to containment. All charges were in Frenchman Flat playa. The time after detonation at which gas venting occurs for the deeper bursts in the Frenchman Flat playa is found to be generally earlier than would be expected from a burst at the same depth in desert alluvium. In this respect, the playa behaves more like a soft rock in which cracks open up early in the motion and allow venting of the high explosive gases to the atmosphere. For shallow burial depths, the time of venting seems to fall closer to that for alluvium. Initial vertical velocities of the free surface as determined by this project are higher in playa than in alluvium. Based on the velocities determined by this project, one calculates that earth stresses a given distance from the charge are less in playa than in alluvium but that stresses at the crater edge are higher because of the smaller crater in playa than in alluvium.

154 (SC-RR-64-1704) PROJECT AIR VENT: CRATER STUDIES. Flanagan, T. J. (Sandia Corp., Albuquerque, N. Mex.). Apr. 1966. 98p. Dep.

Project Air Vent consisted of 30 high explosive cratering shots in the playa of Frenchman's Flat in Area 5 at the Nevada Test Site. The largest shot, with a charge weight of 40,000 pounds was buried at a depth of 17.1 feet. Eleven others were half-buried with charge weights varying from 64 to 6000 pounds. The remaining 18 were buried at varying depths, all with a charge weight of 256 pounds. The data gathered from the 11 surface shots indicate that scaling of apparent crater radius is proportional to the 0.359 power of the charge weight. If the data from the 40,000-pound, Flat Top surface shots are included, the scaling factor becomes 0.369. Craters from the 18 shots at varying depths are generally 20 percent smaller in apparent radius than comparable shots in Area 10 alluvium. The crater from the largest shot, when compared with the 40,000-pound Stagecoach No. 2 shot in Area 10, is smaller by 5 percent in apparent radius and depth.

155 (SC-RR-66-324) CRATERS FROM SHORT-ROW CHARGES AND THEIR INTERACTION WITH PREEXISTING CRATERS. Vortman, L. J. (Sandia Corp., Albuquerque, N. Mex.). July 1966 (Contract AT(29-1)-789. 82p. Dep. mn.

All charges were buried at a depth which would maximize single-charge crater dimensions, and adjacent charges were separated by a uniform distance between 1 and 1.1 times the maximum single-charge crater radius. Short rows of simultaneously detonated charges produced craters which differed only slightly from single-charge craters in volume per charge and in width and depth. Ejecta perpendicular to the row was appreciably greater than the average ejecta for a single charge, but each additional charge beyond the second charge made a smaller contribution to the lateral ejecta than did its predecessor. As expected, ejecta off the end ordinarily did not exceed that for a single charge. One, two, or five charges were detonated simultaneously adjacent to the preexisting craters formed by one, two, three, or five charges. Crater dimensions were not appreciably different because of the pre-existing craters, but the detonation of two or five charges against craters from three or five charges, respectively, caused a barrier to be formed in the near end of the pre-existing craters. Preferential venting in the direction of the pre-existing crater caused a preponderance of ejecta to be distributed in that direction. The barrier was larger for the large number of charges.

156 (SC-RR-66-416) A SMALL-SCALE INVESTIGATION OF EXCAVATION WITH PARALLEL ROWS OF EXPLOSIONS. PART II. Vortman, L. J. (Sandia Corp., Albuquerque, N. Mex.). Oct. 1966. Contract AT(29-1)-789. 50p. Dep. mn.

An earlier experiment, in which craters were made by simultaneously detonating parallel rows of charges, was continued using smaller spacing between charges in the rows and between the rows themselves, together with greater burial depth, in an effort to achieve a more effective use of explosive in terms of apparent crater volume per unit of energy than had been observed for three similar rows detonated separately. Although an increase in volume per unit of energy over the simultaneously detonated rows of charges was observed, the cratering effectiveness of three rows separately detonated was not achieved. Permanent vertical and horizontal displacement of the surface near the crater edge could not be correlated with any of the more obvious variables. Patterns of ejecta from the explosion seemed unrelated to charge spacing or burial depth, but displayed an azimuthal relationship about the multiple rows similar to that observed for single rows. When two rows of charges were detonated simultaneously, there was no notable difference between craters formed with the charges in one row were directly opposite those in the other row, and where the charges in one row were offset one-half space from those in the other.

157 (SC-RR-66-477) CRATERS FORMED BY ROW CHARGES IN THE VERTICAL FACE OF A 90-DEGREE WEDGE. Harris, Virgil A. (Sandia Corp., Albuquerque, N. Mex.). Nov. 1966. Contract AT(29-1)-789. Dep. mn.

An experiment was conducted to simulate a small-scale overburden stripping by nuclear explosives as the technique might be used to facilitate open-pit mining of oil shale as it occurs near valleys in the Colorado Plateau, and to investigate the changes in crater dimensions and ejecta dispersion with changes in burial depth. Five rows of charges, each containing six 8-pound spheres of cast TNT spaced 4 feet apart, were buried 3.0 feet back from the face of a cliff bank. Charges for each of five shots were buried at depths of 3, 3.5, 4, 4.5 and 5 feet, respectively, and all charges for each shot were detonated simultaneously. Results were restricted by the physical limitations of the terrain used for the experiment. The data imply that too shallow a cut beneath the cliff bank might have restricted the vertical dimensions of the apparent crater. As charge burial depth was increased, horizontal apparent crater radius showed no significant change; vertical apparent crater radius became smaller as did crater depth below the charges; and crater volume decreased. A similar experiment could explore the possibilities of a second row of charges to strip additional overburden. The larger portion of the ejecta moved in the direction of the lower elevation, and the percentage moving in that direction increased with increased burial depth. About 9.9 cubic feet of ejecta per pound of explosive resulted from charges of equal burial depth and distance from face of cliff, almost 1.5 times the average of 6.4 cubic feet per pound of explosive from a previous experiment with charges in level ground.

158 (SC-RR-66-480) CRATER, EJECTA, AND AIR-BLAST STUDIES FROM FIVE HIGH-EXPLOSIVE CHARGES IN A HORIZONTAL SQUARE ARRAY. Rappleyea, C. Annette (Sandia Corp., Albuquerque, N. Mex.). Apr. 1967. Contract AT(29-1)-789. 158p. Dep.

Fifteen shots, each consisting of five 64-pound spherical charges of cast TNT buried at depths of 6, 8, or 10 feet, were detonated in dry-lake playa at the Tonopah Test Range. Charges were arranged in a horizontal square array with the fifth charge in the middle and with spacings on the side of the square ranging from 8 to 18 feet. One shot using five 8-pound charges and one using five 256-pound charges were fired at the same cube-root scaled burial depths and spacings as one of the shots using a 64-pound charge. Crater dimensions, air blast, ejecta areal distribution, and permanent displacement of the ground surface were measured. The apparent crater volume for the five 64-pound charges was about three times that from a single 320-pound charge detonated at the same depth. The apparent crater radius from five 64-pound charges was 1.5 times that from a single 320-pound charge. Peak overpressures were as much as 1/10 those for a single 320-pound charge at the same burial depth. A distinctive ejecta pattern showed four mounds formed along the flat sides of the square containing amounts of ejecta that varied with depth of burst. Permanent ground motion was irregular but showed a net inward radial motion in many cases.

159 (SC-RR-67-3) CRATERS FROM ROW CHARGES INTERRUPTED BY A DUD. Vortman, L. J. (Sandia Corp., Albuquerque, N. Mex.). Feb. 1967. 32p. Dep.

Four rows of 64-pound charges were detonated with one charge omitted to determine the effect of a dud in a row of simultaneously detonated charges, for the purpose of providing information on which to estimate the cost of remedying the consequence of a dud and, in turn, the cost justified for a further reduction of probability of a misfire. The barrier formed at the location of the dud was similar, irrespective of the position of the dud in the row. The barrier height was nearly to the original ground level and its volume averaged 40 percent greater than the crater volume excavated by a single charge in the row. Four additional shots using 1, 3, or 7 charges were fired to examine the effectiveness of barrier removal. The effectiveness increased with the number of charges used, and one or three charges left residual barriers, the height of which was respectively one-half and one-fourth the average crater depth. These results are evidence that the consequences of a dud can be repaired by additional explosions.

160 (SC-RR-67-727) CRATER FROM AN INDIVIDUALLY DETONATED MULTIPLE-CHARGE ARRAY. Vortman, L. J. (Sandia Corp., Albuquerque, N. Mex.). Nov. 1967. 56p. Dep.

Air blast and seismic safety considerations may not always permit efficient excavation by simultaneous detonations. To determine whether comparable excavation could be achieved by detonating smaller charges one at a time (nibbling), twenty-five 64-pound charges in a special array were detonated one at a time, followed by a similar detonation of eleven more charges at a row in the bottom of the crater formed by the first twenty-five. The results prove conclusively that in principle nibbling will work to reduce source strength while achieving an excavation goal. The nibbling method provides nearly 50 percent less crater volume than a single charge because of backfilling from subsequent detonations.

161 (SC-RR-67-728) COMPARISON OF CRATERS FROM ROWS OF CHARGES DETONATED SIMULTANEOUSLY AND ONE AT A TIME. Vortman, L. J. (Sandia Corp., Albuquerque, N. Mex.). Nov. 1967. Contract AT(29-1)-789. 44p. Dep.

Row charges made up of 64-pound spherical TNT charges were detonated in one instance simultaneously and in the other instance one-at-a-time in sequence for combinations of two spacings and three burial depths. Where the charges were detonated one at a time, the crater volume was reduced to nearly 50 percent of the volume for the comparable simultaneous detonation. There was not much difference for the combinations of burial depth and spacing tested. The craters from one-at-a-time detonations averaged about 35 percent larger for the greater spacing than for the smaller spacing versus only about 10 percent difference when the charges were fired simultaneously.

162 (UCRL-Trans-10138) FORMATION OF AN EXCAVATION BY A 1009 t THROW-OUT BLAST. Dashkov, A. N. Translated by J. Bradley for Univ. of California, Lawrence Radiation Lab., Livermore, from Transp. Stroit., 10: No. 11, 10-12(1960). 11p. Dep.

A 1009 ton throw-out blast was used to excavate an earth cut for a railway. The planning and blasting technique are described. The results are evaluated in terms of cost, safety, and how closely the desired excavation contour and volume were achieved. This large scale throw-out blast demonstrated the high efficiency of producing excavations by blasting.

163 (UCRL-Trans-10140) EXPLOSION. Pokrovskii, G. I. Translated by T. Lazar for Univ. of California, Lawrence Radiation Lab., Livermore, from Vzryv, Izdatel'stvo Nedra, Moscow, 1964. 171p. Dep.

A general review of the physical nature of explosions is presented in a form intended for readers in all professions. A brief history of the use of explosives is followed by a discussion of types of explosives, their sensitivity, methods of initiation of explosions, and the hydrodynamic theory of explosions. Explosions in air and water and the resulting shock waves are described in some detail. Uses of explosives in mining, in construction, and in molding of materials are discussed.

164 (UCRL-Trans-10141) AVALANCHE, HALT: THE MEMOIRS OF A BLASTER. Dokuchaev, Mikhail. Translated by T. Lazar for Univ. of California Lawrence Radiation Lab., Livermore, from Lavina, Ostanovis: (Vospominaniya Vzrynika), Isdatel'stov, Sovetskaya Rossiya, Moscow, 1965. 137p. Dep.

The phenomena and techniques of industrial blasting are described. Blasting as used to break rock in mining ores and quarrying construction materials; breaking ground to build canals, dams, and reservoirs; fracturing and forging metals; demolishing old buildings; uprooting tree stumps; deepening river beds; and building islands in the sea is discussed.

165 (UCRL-Trans-10188) TECHNICAL PROJECT OF BLAST FOR THE CONSTRUCTION OF THE BOYPAZY DAM ON THE RIVER VAKHSH. Agareva, E. N. Translated by T. Lazar for Univ. of California Lawrence Radiation Lab., Livermore, from Tr. Sess. Uch. Sov. Narodnokhoz. Ispol'z. Vzryva, 5th, Frunze, Kirg. SSR, 1963, 254-8(1965). 13p. Dep.

Cost analysis, explosion plans, and expected results from a project to create a reservoir for irrigating the Yavanskaya and Obi-Kükskaya valleys are discussed. Two charges of explosives located on the right bank of the Vakhsh River on either side of the dam axis are to be used to blast out dense stratified limestone from the steep right bank of the river to form a closed rock-filled dam 55 m high.

D. NUCLEAR EXPLOSIVE EXPERIMENTS

1. Project Palanquin

Reports

166 (AD-631340) PALANQUIN. Long Range Seismic Measurements [of] VELA UNIFORM. Seismic Data Laboratory Report No. 144. (Teledyne Industries, Inc., Alexandria, Va. Earth Sciences Div.). Apr. 18, 1966. Contract AF 33(657)-15919. 37p.

An analysis of seismological data from an underground nuclear explosion is presented as a continuing study to provide information to aid in distinguishing between earthquakes and explosions. A table of travel-times and amplitudes of P, Pg, Lg, and surface waves are included along with other unidentified phases.

167 (PNE-900F(Rev.1)) GROUND MOTION. Project PALANQUIN. Rohrer, R.; Terhune, R. W. (California Univ., Livermore. Lawrence Radiation Lab.). Aug. 1967. Contract W-7405-eng-48. 46p. Dep.

Data concerning the surface motion as a function of time for the Palanquin nuclear cratering event are presented. A description of the experimentation and the general surface motion is given. The data for the surface motion time history are obtained from reading and analyzing, by means of digital computer, the film from high-speed photography of surface motion. Graphs of the vertical and horizontal displacement and vertical velocity of individual surface motion targets vs time are presented.

168 (PNE-904) PROJECT PALANQUIN: STUDIES OF THE APPARENT CRATER. Final Report. Videon, Fred F. (Army Engineer Nuclear Cratering Group, Livermore, Calif.). Apr. 1966. Contract W-7405-eng-48. 34p. Dep. mn.

Project Palanquin was a low yield nuclear detonation conducted by the Lawrence Radiation Laboratory as a part of the AEC Plowshare Program. The device was detonated in a porphyritic trachyte flow of the Ribbon Cliff Rhyolite formation, a hard dry rock, at a scaled depth of burst of 55.6 meters/$kt^{1/3.4}$. Since the depth of burst was deeper than that which results in maximum apparent crater dimensions in rock, it was predicted that the detonation

would result in a rubble mound rather than a crater below ground surface. Detonation of the Palanquin device produced an apparent crater 72.6 meters in diameter and 24.0 meters deep. The production of an apparent crater was probably the result of scour by the escaping gas which vented prematurely. The asymmetry of the crater and the surrounding disturbance of the ground surface indicate the influence of geology in producing the crater. The crater is nearly hyperbolic in cross section, and the maximum inclination of the slopes of the crater walls is about 35 degrees. The lip of the Palanquin crater resulted primarily from an upward displacement of the original ground surface. The distance to the edge of this uplifted zone is about twice the depth of burst. This extent of uplift agrees well with the results of the Sulky detonation (device detonated at scaled depth of 56.5 meters/$kt^{1/3.4}$). The magnitude of the vertical displacement of the lip of the Palanquin crater, however, was less than that for Sulky.

169 (PNE-913F) ANALYSIS OF SURFACE SEISMIC DATA. Project PALANQUIN. Davis, Lawrence L. (Beers (Roland F.), Inc., Alexandria, Va.). Dec. 7, 1965. Contract AT(29-2)-1163. 60p. Dep. mn.

Palanquin was the first nuclear event at Pahute Mesa and also the first nuclear cratering test in rhyolite. A program of instrumentation was designed for recording the ground motions from this unique event. Peak ground motions were predicted for each station so that the instruments could be set at the proper recording levels. The distances at which the peak acceleration would be 0.1 g and 0.001 g were predicted. The recorded peak values of ground motion are presented in tabular and graphical form. Where appropriate, least-squares regression equations were fitted to the data. Comparisons of the observed data with the appropriate prediction equation show that the predictions were higher than the observed acceleration and velocity and lower than the observed displacement. However, the differences are small and the prediction equations are considered adequate for the present time. Data obtained will be useful in the future for scaling determinations and also for comparison of ground motions from cratering and contained events.

2. Project Sedan

Published Literature

170 INFLUENCES OF A THERMONUCLEAR CRATERING TEST ON CLOSE-IN POPULATIONS OF LIZARDS. Turner, Frederick B.; Gist, Clayton, S. (Univ. of California, Los Angeles). Ecology, 46: 845-52(Autumn 1965).

On July 6, 1962, a large thermonuclear device was detonated at the Nevada Test Site (Project Sedan). It was buried 635 ft underground and had a total yield of 10 kt. The explosion ejected about 7.5 million yd^3 of alluvium and produced a crater 320 ft deep and 1200 ft in diameter. As a part of an investigation of the ecological influences of underground detonations, a study was made of lizard populations within 10,000 ft of ground zero. Adult Cnemidophorus tigris, Crotaphytus wislizeni, and Uta stansburiana were exterminated within 4000 ft from ground zero. Very few adult lizards of any species were observed within 6000 ft. No changes attributable to the test were detected at 8500 to 9000 ft. Eggs of the three species hatched following the test in areas where adults did not survive. Young Uta stansburiana were numerous in August from 2600 to 9000 ft from ground zero. By October, the young lizards at 2600 ft were gone, and mortality at 3800 ft was extremely heavy. At 9000 ft the apparent density of young Uta was only slightly reduced as compared to that in August. In June, 1963, adults of the three species were observed between 4500 and 5000 ft from ground zero, and Uta was apparently most abundant. It is possible that Cnemidophorus was more sensitive than Uta to the deleterious influences. The immediate mortality within 4000 ft is attributed to the gross physical effects of the detonation (dirt fall and blast) which destroyed all of the vegetation out to 2000 ft and caused partial damage to 5000 ft. Delayed mortality, as that exhibited by juveniles which hatched after the test, is attributed to destruction of habitat. Neither the depletion of food resources nor the residual radiation is likely to have been lethal. Absorbed tissue doses, as registered by three microdosimeters implanted in lizards before the test and recovered July 28, were probably significantly less than the free-air dose registered in the same area.

171 NEUTRON ACTIVATION PRODUCTS FROM PROJECT SEDAN IN PLANTS AND SOILS. Romney, E. M.; Rhoads, W. A. (Univ. of California, Los Angeles). Soil Sci. Soc. Amer., Proc., 30: 770-3(Nov.-Dec. 1966). (UCLA-12-589).

Neutron activation products of tungsten, scandium, and antimony were among those radionuclides concentrated through roots of plants grown on ejecta from the Sedan thermonuclear cratering detonation. Nuclear reactor-produced isotopes were used in corroborative experiments to investigate, in greater detail, their behavior in plants and soils. Radiotantalum was also included as a matter of academic interest. Plants concentrated more ^{46}Sc, ^{24}Sb, and ^{185}W in leaves than in stems, whereas ^{182}Ta was concentrated more in stems. Plant uptake of ^{46}Sc, ^{124}Sb, and ^{185}W was influenced by different types of soil. Scandium-46 and ^{182}Ta were virtually immobile in columns of soil leached with 76 cm of water while ^{124}Sb and ^{186}W moved readily in neutral and alkaline soil, but not in acidic soil. Their behavior was influenced by the kind of clay mineral present, the sodium and potassium content, and the soil pH.

Reports

172 (CEX-62.80c) SEDAN PROJECT 62.80c, AERORADIOACTIVITY SURVEY. (Edgerton, Germeshausen and Grier, Inc., Santa Barbara, Calif.). Nov. 1965. Contract AT(29-1)-1183. 16p. (EGG-1183-2062). Dep.

The distribution of Sedan fallout deposited on the ground from 10 to 200 miles from ground zero was determined. The fallout was shown by dose-rate contours to be asymmetric, with a steep gradient west of the midline and a very gradual gradient on the east. Gamma energy measurements made 100 ft above the ground resulted in the identification of ^{131}I, ^{132}Te, ^{132}I, ^{187}W, and ^{140}Ba-^{140}La.

173 (PNE-200-F) FINAL OFF-SITE REPORT OF THE PROJECT SEDAN EVENT, JULY 6, 1962. PLOWSHARE PROGRAM. Placak, O. R. (Public Health Service, Las Vegas, Nev.). Dec. 12, 1962. 85p. Dep.

The Project Sedan event was conducted as a part of the Plowshare Program at 1000 hours on July 6, 1962, in Area 10 of the Nevada Test Site by the Lawrence Radiation Laboratory. The Project Sedan nuclear cratering experiment resulted in the formation of a radioactive cloud which drifted northward on a 10 degree bearing for 40 miles to the vicinity of Queen City Summit, and then moved on a 20 degree bearing to Ely. From here, a nighttime wind shift carried the cloud eastward. The highest estimated total infinite exposure dose received at a populated location from the Project Sedan event was 945 mR at Diablo (population eight), and the second highest was 226 mR at Penoyer (population two). These are calculated infinite doses. Personal film badges worn by the residents and collected on July 9, 1962, indicate 150 to 170 mR dose at these two locations. In order to ensure a minimum of exposure, the people at these two locations and Tempiute (population three), were relocated during cloud passage. The results of monitoring and environmental sampling efforts conducted by the U. S. Public Health Service Off-Site Radiological Safety Organization are presented.

174 (PNE-225F) PROJECTS 62.86 AND 62.80. PART I. CHARACTERISTICS OF FALLOUT FROM A DEEPLY BURIED NUCLEAR DETONATION FROM 7 TO 70 MILES FROM GROUND ZERO. PART II. AERIAL RADIOMETRIC SURVEY. Project SEDAN. Mork, Harold M.; Larson, K. H.; Kowalewsky, B. W.; Wood, R. A.; Paglia, D. E.; Rhoads, W. A.; Guillou, R. B. (California Univ., Los Angeles. Lab. of Nuclear Medicine and Radiation Biology). July 1966. Contract AT-04-1-GEN-12. 118p. Dep. mn.

Adequate samples of fallout from the detonation of a nuclear device buried in desert alluvium at 635 feet below ground surface were obtained to delineate the eastern part of the fallout pattern from 7 to 70 miles from ground zero. The distribution of radioactivity per unit area, mass per unit area, and mass per unit area per particle size fraction were determined. No correlation between radioactivity and mass was found. The time of arrival of fallout and radiation intensity histories were recorded by field radiation detection instruments. Considerable differences occurred in time of arrival of fallout and its duration across the fallout pattern beyond 20 miles from ground zero. Radioactive decay of samples from five laterals of the fallout pattern showed negative slopes of about 1.4 for the time interval from H + 48 to H + 600 hours. Enough shear of the cloud occurred to permit a comparison of the isotopic fractionation existing above 10,000 feet MSL; but the data are limited to incomplete results from only five samples, one from each lateral, submitted to NRDL. The radiochemical analyses indicated a distance relationship and provided evidence of fractionation that substantiated a difference between the fallout debris from two levels of the cloud. The data indicated that topography had a significant influence on the activity per unit

mass, the particle size distribution and the fractionation of the fission product nuclides. The Aerial Radiometric Surveys determined the distribution of Sedan fallout to a distance of more than 200 miles from ground zero. The dose rate contours show the pattern to be asymmetric with a steep gradient west of the midline with a very gradual gradient on the east.

175 (UCRL-50360) RESIDUAL TRITIUM AT SEDAN CRATER. PART II. SOIL AND EJECTA STUDIES. Koranda, John J.; Martin, John R.; Wikkerink, Robert (California Univ., Livermore. Lawrence Radiation Lab.). Dec. 7, 1967. 42p. Dep.

Continuing studies of residual tritium in soil or ejecta deposited on the landscape around the Sedan crater, Nevada Test Site, are concerned with the spatial and temporal distribution of THO in the area from the crater lip to 5000 ft from ground zero. Seasonal variations in the concentrations of tritium in soil water occur mainly during the winter rainfall period. Dilution effects were observed to a depth of 3 ft during an unusually high rainfall period (1965 to 1966). Diluted tritium concentrations in the surface strata of soil (6 in. to 3 ft) increase to almost the predilution levels during the summer as a result of soil moisture movements. When Sedan ejecta occurs as a shallow layer overlying the preshot soil, maximum tritium concentrations are found in this soil, usually at the maximum depth of rainfall penetration, or approximately 3 ft. Maximum concentration of tritium in ejecta on the Sedan crater lip is found at a depth of 4 to 5 ft and is correlated with the depth of ejecta materials found around the crater lip. An inventory of tritium in the Sedan ejecta field was calculated, based upon collections of soil samples along transects of the ejecta-covered area, and to a depth of 6 ft at each site. The tritium inventory measurements are essentially of biologically available water in the soil system. When data are corrected to total soil-water tritium values, the current inventory of tritium outside the Sedan crater in 1967, five years postshot, is 5 to 6% of the estimated inventory of the residual tritium in the ejecta at shot time.

176 (UCRL-70292) RESIDUAL TRITIUM AT SEDAN CRATER. Koranda, John J. (California Univ., Livermore. Lawrence Radiation Lab.). Apr. 2, 1967. Contract W-7405-eng-48. 36p. (CONF-670503-9). Dep.

From 2nd National Symposium on Radioecology, Ann Arbor, Mich.

Residual tritium from the Sedan thermonuclear detonation, July 6, 1962, was scavenged by or entrained in the 5 to 6 million tons of earth materials moved by the detonation. As a result, the Sedan post-shot environment contained a most significant biological tracer in the form of THO. Residual tritium (THO) is found in μCi concentrations in the interstitial water of the Sedan throwout soil, and in the loose tissue water of plants that have re-invaded the new substratum deposited on the landscape adjacent to the crater. Tritium is present not only in the loose tissue water of vascular plants growing on the Sedan throwout, but a comparable level is also found in the tissue-bound hydrogen of these plants. Herbivores, mainly heteromyid rodents, which have re-invaded the Sedan post-shot environment and reside there, also have tritium concentrations in their body water between 1 and 3 μCi/ml. These body-water tritium concentrations are closely related to the levels of tritium in the plant tissue-bound hydrogen. Soil-water tritium concentrations in the soil air at the rodent burrow depth are several orders of magnitude lower than the observed body-water level. The inspirational route of entry of tritium into the animal is therefore assumed to be a secondary one, with the primary source being the plant organic matter synthesized in the Sedan post-shot environment which is used as the animal's food base. The internal dose to the resident mammal at Sedan Crater from residual tritium is estimated to be between 18 and 268 RAD, or about 10 times that from external radiation sources resulting from the detonation. Part I of UCRL-50360, Part II.

177 (UCRL-70630) LEACHING OF RADIONUCLIDES AT SEDAN CRATER. Koranda, John J.; Martin, John R.; Wikkerink, Robert W. (California Univ., Livermore. Lawrence Radiation Lab.). Mar. 25, 1968. Contract W-7405-eng-48. 44p. (CONF-680308-12). Dep.

From 155th National Meeting of the American Chemical Society, San Francisco, Calif.

The distribution of tritium and long-lived gamma radioactivity in crater ejecta from the Sedan detonation was studied. Tritium concentrations were determined in soil water extracted from crater ejecta samples collected from the surface to six feet, and at distances of 3000 feet from the crater. The distribution of tritium was very obviously modified by postshot environmental effects, especially rainfall leaching. Tritium maximum concentrations were found below the strata in which they were deposited. Gamma radionuclides exhibited limited movement in the crater ejecta strata or in preshot soil covered by Sedan ejecta. A subtle leaching of ^{137}Cs was demonstrated by considering the $^{137}Cs/^{54}Mn$ ratios in the ejecta strata.

3. Project Sulky

Reports

178 (PNE-710F) SCIENTIFIC PHOTOGRAPHY. Project SULKY. Final Report. Brower, R.; Wilson, D. (Edgerton, Germeshausen and Grier, Inc., Las Vegas, Nev.). Aug. 25, 1965. Contract AT(29-1)-1183. 125p. Dep. mn.

Sulky, a Plowshare experiment, was detonated 1135 hours, December 18, 1964, on Buckboard Mesa, Nevada Test Site. The Sulky explosive was a 90 ton nuclear device buried to a depth of 90 feet in basalt. Scientific photography designed to measure ground surface motions, base surge growth, and cloud evolution is described. The Sulky technical photographic instrumentation systems performed as programmed. Mission objectives were met; data were obtained from which quantitative measure of surface motion, base surge and cloud phenomena could be made.

179 (PNE-713F) CRATER MEASUREMENTS. Project SULKY. Videon, F. F. (Army Engineer Nuclear Cratering Group, Livermore, Calif. California Univ., Livermore. Lawrence Radiation Lab.). Oct. 1965. Contract W-7405-eng-48. 37p. Dep. mn.

Project Sulky was the detonation of an 85-ton nuclear device in basalt at a depth of burst of 27.4 meters. The detonation produced a mound of broken rock with a depression in the center. The base of the mound was roughly circular in plan and had a radius of 24.2 meters. The radius of the crest of the lip around the ejecta was 8.87 meters and the average height of the lip crest above preshot ground surface was 6.31 meters. The bottom of the depression was 2.80 meters above the preshot ground elevation. The preshot ground surface was uplifted and cracked to a distance of approximately 52 meters from surface zero. The height of the upthrust was 1 meter at the base of the rubble mound. Based on the results of Sulky and other cratering data for basalt, the following conclusions have been made concerning cratering in hard, dry, inert rock: (1) In the region of depths of burst somewhat deeper than optimum, nuclear explosives are less effective than high explosives for apparent crater production. (2) Apparent crater dimensions diminish rapidly as the depth of burst increases beyond optimum. (3) The apparent lip height, the true crater radii and the extent of upthrust beyond the true crater are similar for both nuclear and high explosive craters in basalt.

180 (PNE-715-F) FINAL REPORT OF OFF-SITE SURVEILLANCE FOR PROJECT SULKY. (Public Health Service, Las Vegas, Nev. Southwestern Radiological Health Lab.). Mar. 9, 1965. 14p. Dep.

The Public Health Service provided off-site surveillance for Project Sulky which was conducted at 1135 hours on December 18, 1964. The highest gamma dose rate recorded off-site was 0.06 mr/hr and no fresh fission products were detected in air, water or milk samples collected subsequent to this event. No exposures exceeded the radiological safety guides set forth in the AEC Manual Chapter 0524.

181 (PNE-717F) ON-SITE RADIOLOGICAL SAFETY REPORT. Project SULKY. McClendon, Leslie (comp. and ed.) (Reynolds Electrical and Engineering Co., Inc., Mercury, Nev.). July 1965. Contract AT(29-2)-162. 59p. Dep. mn.

A nuclear cratering experiment in hard rock, executed as a part of the program for the development of nuclear excavation, is described. The purposes of the experiment were: (1) to determine the distribution of radioactivity produced at a greater scaled depth than Danny Boy, which would provide basic input for the design of follow-on larger yield experiments in a similar medium; (2) to determine the concentration of certain radionuclides airborne at various distances; and (3) to produce crater mechanics information at a greater scaled depth than Danny Boy. Appropriate precautions were taken to protect individuals from unnecessary exposure to radiation. Remote radiation measurements were taken during and after the event by a telemetry system, and monitors with portable instruments surveyed the route into ground zero before other planned entries were made. The following measurements were taken and recorded: telemetry and portable instrument measurements of gamma dose rates, radionuclide concentrations in air, and alpha source, toxic gas, and explosive mixture concentrations.

182 (PNE-718-F) FEDERAL AVIATION AGENCY AIR-SPACE ADVISORY. PROJECT SULKY. Final Report. Vick, H. M. (Federal Aviation Agency, Palmdale, Calif. Los Angeles Air Route Traffic Control Center). Aug. 5, 1966. 8p. Dep.

The object of the study was to delineate a sector through which a contaminated air mass is expected to move and through which nonparticipating military and civilian aircraft would be advised not to fly. The Federal Aviation Agency concluded that the Project Sulky Air Space Advisory Plan provided all proper precautions necessary to ensure against radioactive contamination of airmen or aircraft.

183 (PNE-720F) GEOLOGIC AND ENGINEERING PROPERTIES INVESTIGATIONS. Project SULKY. Final Report. Lutton, R. J.; Girucky, F. E. (Waterways Experiment Station, Vicksburg, Miss.). Sept. 1966. 131p. Dep.

The Sulky event was a nuclear cratering experiment in which a device yielding 85 ± 15 tons was detonated at a depth of 90 feet in jointed basalt. The explosion produced a rubble-covered mound roughly circular in plan and extending approximately 24 feet above the original ground surface. Prior to the event the Sulky site was explored by means of six core borings and the emplacement calyx hole. Geophysical logging was conducted and laboratory tests were performed on representative samples. Postshot investigations consisted of trenching through the mound and drilling three core borings to determine the extent of the rupture zone. The rock consists of vesicular basalt over dense basalt and each type is structurally modified by layering of vesicles resulting from viscous flow of the lava. Unconfined compressive strengths range from about 10,000 psi for vesicular basalt to about 20,000 psi for dense basalt. Bulk specific gravities for dense basalt are about 2.74, but with increasing vesicle content the bulk specific gravity reaches values as low as 2.40. Two sets of axes of folds developed during flow of the lava are inferred from flow layer orientation. Subsequent natural joints tend to be parallel or perpendicular to this primary anisotropy and an orthogonal joint pattern emerges for most of the site. This natural pattern influenced the orientation of blast fractures, the orientation of surface fissures, the shape of the crater, and the distribution of rubble (ejecta and fallback) sizes. The gross subsurface effect of the blast was development of a camouflet about 60 feet in diameter surrounded by a ruptured and dilated zone averaging about 200 feet in diameter. The limit of the dilated zone flares near the surface and in the center a chimney of the expanded media is inferred to have subsided and partially filled the camouflet.

III. NATURAL RESOURCES DEVELOPMENT

A. PHENOMENOLOGY AND TECHNOLOGY

Published Literature

184 ATOM AIMS FOR ROLE AS PROSPECTOR. Bus. Week, No. 1946, 83-6(Dec. 17, 1966).

The use of underground nuclear explosions to unlock gas, mineral, and oil reserves is examined from a commercial viewpoint stressing the companies interested in the immediate application, current AEC developments, the costs involved, and feasibility and safety considerations.

185 PROJECT THUNDERBIRD: A NUCLEAR TRIGGER FOR COAL GASIFICATION. Wold, John S.; Woodward, Thomas C. (Wold and Jenkins, Casper, Wyo.). Coal Age, 72: 64-5; 68(Sept. 1967).

Use of nuclear explosions to facilitate utilization of coal, oil shale, and bituminous sand beds is reviewed, with particular attention to Project Thunderbird. A 100-mi^2 region of Wyoming, underlain by more than 20,000 million tons of coal, is the site for this in situ coal-energy experimental program. The total coal interval lies at a depth of from 1000 to 2200 ft and contains a gross section of coal that may be the thickest in the Western Hemisphere. In Project Thunderbird, a nuclear explosion will open up multiple seams and overcome some problems experienced in previous underground gasification experiments. A collapse chimney of 25 to 30% void space could be formed, which would be burned under controlled conditions. A 50-kiloton nuclear device at 2200 ft in the base of the Fort Union coal-bearing unit will give the following chimney characteristics: a rubble chimney of broken rock with a radius of about 127 ft and a height of around 635 ft; fractures extending into the surrounding formation in a radius of 300 ft; and approximately 2,000,000 tons of broken rock of which 25% (or 500,000 tons) is coal (a Btu equivalency of 1.5 million barrels of oil). Ignition of the broken coal and controlled injection of oxygen into the chimney will produce low-Btu gas and associated products.

Reports

186 (UCID-15259) PURGING OF NUCLEAR CHIMNEYS. Cohen, Jerry J. (California Univ., Livermore. Lawrence Radiation Lab.). Dec. 1967. Contract W-7405-eng-48. 17p. Dep.

Contained underground thermonuclear explosions can result in the retention of large quantities of radioactive gaseous contaminants in the nuclear chimney, notably ^{85}Kr and tritium. Prior to using nuclear chimneys for practical applications such as the storage of natural gas, they must be purged of these contaminants as much as possible. Experiments were conducted using standard aircraft oxygen tanks, either empty or filled with different size sand and gravel to simulate hollow or rubble-filled nuclear chimneys. The void volumes were measured. Purging effectiveness was determined by using ^{85}Kr as a tracer in air, and by measurement of the ^{85}Kr content in the chimney effluent. Two types of purging procedures were tested: continuous purging with clean air injected at the bottom of the tank, and pressure cycling purging (repeated pressurization and depressurization through a single access hole). Results indicated that continuous purging is superior to pressure cycling, and that this can be accomplished with a single access hole by using concentric inlet and exhaust tubing. Larger scale experiments are recommended.

187 (UCRL-14756) INDUSTRIAL APPLICATIONS OF CONTAINED NUCLEAR EXPLOSIONS. Rawson, Donald E. (Lawrence Radiation Lab., Univ. of California, Livermore). July 1966. Contract W-7405-eng-48. 59p. Dep. mn.

The phenomena and technology of contained (nonexcavation) nuclear explosions as they relate to potential industrial uses are summarized. The results of nuclear explosions of a given yield, at a given depth, and in a known geologic setting are understood sufficiently that further explosions can be conducted safely and, within limits, the characteristics of the resulting environment can be predicted. The features of contained nuclear explosions that should be of most interest to industry are (1) the creation of a large void underground in the form of a cavity generated by the explosion. This void becomes distributed between rubble fragments when the roof of the unstable cavity collapses; (2) the creation of a large amount of fragmented rock distributed within a chimney that develops as a result of the collapse of the roof of the cavity; (3) the fracturing of rock surrounding the cavity-chimney region and associated increased permeability in most rock types. To illustrate the magnitudes of these effects, a 100-kiloton explosion at a depth of 900 meters (3000 feet) will produce a cavity with a radius of about 45 meters (148 feet) or a void volume of 1.23 million cubic meters (43.5 million cubic feet). Cavity roof collapse will extend about 194 meters (635 feet) above the explosion center and will contain 1.61 million tons of rubble. About ten times this tonnage may be cracked and become more permeable. The environment resulting from a contained nuclear explosion has applications leading to the recovery of oil, natural gas, minerals, water, and geothermal energy; to the underground storage of oil, natural gas, water, and compressed air; and to the disposal of fluid waste.

B. MINING AND MINERALS

Reports

188 (BM-RI-6996) FRACTURING A DEPOSIT WITH NUCLEAR EXPLOSIVES AND RECOVERING COPPER BY THE IN-SITU LEACHING METHOD. Hardwick, William R. (Bureau of Mines, Tucson, Ariz.). Dec. 1966. 51p. Dep.

It appears that copper deposits can be safely fractured with nuclear explosives and the copper successfully recovered by in situ leaching. The process has a high success potential and must be evaluated by a full-scale test before the economics or the extent of the use of the method by the mining industry can be predicted. Preliminary calculations indicate that the cost of fracturing copper deposits with nuclear explosives may range from 1.8 to 55.2 cents per ton. Copper may be recovered by this method at less cost than by conventional methods.

1. Project Sloop

Published Literature

189 SEEK PROFITABILITY ANSWER TO NUCLEAR IN-SITU COPPER LEACHING AT SAFFORD. Hansen, Spenst M.; Rabb, David D. World Mining, 4p(Jan. 1968). (UCRL-70780).

The proposed Sloop experiment to be undertaken jointly by the USAEC and Kennecott Copper for the nuclear in situ leaching of copper ore near Safford, Arizona is described. The topography of the ore deposit and the four phase planning for the experiment are discussed in some detail.

Reports

190 (PNE-1300) SLOOP. Zimmer, Peter F.; Lekas, M. A. (comps. and eds.) (Kennecott Copper Corp., Salt Lake City, Utah. Bureau of Mines, Washington, D. C. California Univ., Livermore. Lawrence Radiation Lab.). June 1, 1967. 44p. Dep.

The feasibility of fracturing low-grade copper deposits with nuclear explosives in preparation for extracting copper by in-place leaching methods is investigated. The study is part of the Plowshare program and includes detailed investigations of both the explosive fracturing and the leaching aspects, and includes the design of an experiment (Project Sloop) to field test the application. A low-grade copper deposit was investigated as a possible site to test the concepts. The results indicate that a deeply buried nuclear explosive can adequately fracture a portion of the deposit for the test. Based on previous test work, the ore mineralization should respond favorably to leaching recovery methods. The study also concludes that an effective experiment can be designed which would satisfy both the technical objectives and meet all safety requirements. Possible radioactive contamination of the copper is considered to be a manageable problem both for the experimental and for general application. Radioactivity in the leaching solutions should be at low enough levels that shielding should not be required for personnel protection.

C. OIL AND GAS

Published Literature

191 BUMINES CHIEF SAYS NUCLEAR BLASTS OFFER KEY TO FUTURE SUPPLY. Kinney, Gene T. Oil Gas J., 64: 44-6(Aug. 15, 1966).

The application of nuclear explosives to the recovery of shale oil and natural gas is discussed. Project Gasbuggy, a cooperative effort between the USAEC and the El Paso Natural Gas Company to investigate the use of nuclear fracturing for the production of natural gas, is described. The use of nuclear fracturing for the production of shale oil is also discussed.

192 CAN NUCLEAR RETORTING UNLOCK OIL SHALE. Eng. Mining J., 168: 72-5(Dec. 1967).

Project Bronco, a nuclear blast in Colorado oil shale to demonstrate the feasibility of underground fracturing and in-place retorting, is discussed. The tentative site on government-owned oil shale land in the Piceance Creek Basin contains as much as a 2000-ft thick oil shale horizon. Dawsonite ($NaAlCO_3(OH_2)$), nahcolite ($NaHCO_3$), and halite, potential byproduct sources of soda ash and alumina that have only recently been identified in the Green River structure, are comingled with oil shale in the relatively impermeable lower zone of the Parachute Creek member. The lower zone is overlain by a leached, water-bearing zone of oil shale. A nuclear explosive with a yield of about 50 kt is anticipated for Bronco. The assumed depth of emplacement at 3350 ft is considered more than adequate to ensure containment of the explosive energy. The nuclear device would create a collapse chimney 230 ft in dia which would extend to a height of 520 ft. Fractures caused by the explosion would extend as much as 460 ft laterally beyond the collapse zone and as far as 700 ft above the shot point. The upper level of the fracture zone would be about 2650 ft underground. Most of the radioactive materials resulting from the explosion would condense, cool, and solidify in a glassy puddle at the bottom of the cavity. The chimney rubble would contain a bulk porosity of about 25% and as much as 1 Mt of fragmented oil shale. If the average oil content were 24 gal/ton, the chimney itself would contain more than 600,000 bbl of oil. The proposed experiment is to be staged in 4 phases: evaluation of the proposed site from a technical and safety point of view; construction to prepare the nuclear explosion, the detonation, and postshot evaluation; chimney retorting; and an attempt to extend the retorting process to a portion of the fractured zone surrounding the chimney.

193 FRACTURING OIL SHALE WITH NUCLEAR EXPLOSIVES FOR IN-SITU RETORTING. Lekas, M. A. (Atomic Energy Commission, Berkeley, Calif.); Carpenter, H. C. Quart. Colo. Sch. Mines, 60: No. 3, 7-30(July 1965).

Preliminary concepts are discussed for using either fission or fusion (preferably fusion which results in fewer contamination problems) nuclear devices to fracture oil shale deposits. Nuclear devices would be used to create multiple NTU retorts underground for extracting the oil from the shale. The shale would be burned in underground retorts with the oil being collected in the lower part of the collapse chimney and drawn off through drainage drifts or wells. A concept of a commercial scale operation based upon a fragmentation array in a 1000 ft thick shale bed is presented. Various specifications and costs are presented for several sizes and types of nuclear devices.

194 FRACTURING WITH NUCLEAR DEVICE WILL RESOLVE UNANSWERED QUESTIONS. Brinkoeter, W. R. (Keplinger and Associates, Houston, Tex.). Oil Gas J., 65: No. 25, 127-32(June 19, 1967).

The use of nuclear explosions to stimulate the production of oils and gases is discussed. Three research projects—Projects Dragon Tail, Gasbuggy, and Rulison—are described. These projects should provide answers to many technological problems relating to nuclear fracturing and should aid in developing nuclear explosives as a practical tool for the oil and gas industries. The use of nuclear explosives in nuclear fracturing is discussed under the following headings: economics, location, burial depth, formation thickness, radioactivity, and political aspects.

195 HOW NUCLEAR EXPLOSIONS CAN BOOST GAS-STORAGE CAPACITY. Atkinson, Charles H.; Ward, Don C. (Bureau of Mines, Bartlesville, Okla.). Oil Gas J., 64: 102-5 (Aug. 22, 1966).

The need for gas-storage capacity near metropolitan areas opens new fields of study as part of the Plowshare program. Results show that the cost of storing gas in cavities formed by nuclear explosives will be less than for liquefied natural gas or mined cavity storage. Under current study are problems which may arise from radioactivity and seismic shock, and the feasibility of a field test.

196 NUCLEAR STIMULATION OF NATURAL-GAS PRODUCTION. Coffer, H. F.; Aronson, H. H. (Geonuclear Corp., Las Vegas, Nev.). Trans. Amer. Nucl. Soc., 9: 311-12(June 1966).

197 OIL, GAS PROJECTS PERK UP AEC'S PLOWSHARE. Chem. Eng. News, 45: No. 6, 44-6(Feb. 6, 1967).

The economics of the AEC's Plowshare Project Gasbuggy is outlined and the industrial potential for the nuclear fracturing technique for natural gas recovery is reported. The engineering progress at the Pictured Cliffs formation is briefly described. Projects scheduled to follow Gasbuggy are Dragon Trail, Bronco, Sloop, and Ketch projects.

198 PETROLEUM'S MOST DRAMATIC RECOVERY EXPERIMENT NEAR. Kinney, Gene T. Oil Gas J., 65: 71-3 (Sept. 4, 1967).

The use of underground nuclear explosions for the production of natural gas is discussed. The experiment, known as Project Gasbuggy, will utilize a 26-kt nuclear explosive detonated in gas-bearing sandstone some 4000 ft below the surface to fracture underground formations so that the entrapped gas will be released. Drilling operations for the emplacement of the nuclear explosive and monitoring and instrument holes are summarized. The feasibility and economics of using nuclear explosives to create underground gas storage cavities are also discussed. This experiment called Project Ketch, will utilize a 24-kt nuclear device detonated at a depth of 3300 ft in Devonian sandstone and shale.

199 RECOVERING OIL BY RETORTING A NUCLEAR CHIMNEY IN OIL SHALE. Lombard, D. B. (Lawrence Radiation Lab., Livermore, Calif.); Carpenter, H. C. J. Petrol. Technol., 19: 727-34(June 1967).

A method is proposed for recovering oil by retorting oil shale shattered by deep underground nuclear explosions. Because most of the oil will be obtained from chunks of oil shale with maximum dimensions exceeding 1 ft, retorting times of up to several weeks are needed for complete recovery. A study of the heat economy of the retorting process in an underground nuclear chimney suggests that the nuclear detonation itself and the subsequent controlled combustion of residual carbon in retorted oil shale will provide ample energy. The proposed method is shown to be thermally efficient. The operating conditions of a nuclear chimney retort will be defined by the recycle gas-to-air ratio and the overall rate of gas injection. Determination of optimum operating conditions will be complicated by the many factors involved. However, the proposed technique appears to be a promising one for recovering the oil from thick, deep, oil shale deposits.

Reports

200 (PNE-3006) TECHNICAL AND ECONOMIC POTENTIALS OF SHALE OIL PRODUCTION BY NUCLEAR EXPLOSIVES. Heiss, Klaus-Peter (Mathematica, Princeton, N. J.). Aug. 31, 1967. Contract AT(04-3)-691. 125p. Dep.

The in situ production of oil from shale by large underground retorts created by nuclear explosives is discussed. The process is described, crude oil and oil shale resources are estimated, and cost estimates of this new technology are compared with present crude oil prices and potential costs of conventional shale oil production.

201 (PNE-3007) ECONOMIC POTENTIALS OF NATURAL GAS PRODUCTION STIMULATION BY NUCLEAR EXPLOSIONS. Heiss, Klaus-Peter (Mathematica, Princeton, N. J.). Aug. 31, 1967. Contract AT(04-3)-691. Dep.

The technical and economic potentials of gas stimulation by nuclear explosives are described. A sufficiently firm body of information related to gas stimulation exists to confirm the statement that gas stimulation can become one of the first technically and economically feasible applications of the peaceful uses of nuclear explosives. It appears that gas stimulation can be applied with profit in existing tight gas fields which can not be exploited with conventional techniques. If the existing information is confirmed experimentally, the peaceful application of nuclear explosives would increase the United States recoverable natural gas resources by amounts greatly in excess of known supplies. Specifically, it appears that the increase would extend the present supply of gas by adding a supply of at least 18 years. The true figure might in fact exceed 55 years additional supplies, even allowing for a substantial annual increase in demand by the United States economy.

202 (SC-RR-65-657) THREE POSSIBLE ENGINEERING APPLICATIONS OF NUCLEAR EXPLOSIVES IN THE SHALE OIL INDUSTRY. Smith, R. E. (Sandia Corp., Albuquerque, N. Mex.). Oct. 1966. Contract AT(29-1)-789. 25p. Dep. mn.

Three methods are described by which nuclear explosives might be used to enhance the obtaining of petroleum products from shale oil deposits. The three methods are construction of an underground retort by nuclear explosives, limited use of the nuclear block cave mining methods to enhance an in situ combustion recovery operation, and limited use of the nuclear block cave mining method to make an open pit mining method feasible.

203 (TEI-868) LOCATIONS OF POTENTIAL INTEREST FOR FRACTURING OIL SHALE WITH NUCLEAR EXPLOSIVES FOR IN SITU RETORTING, PICEANCE CREEK BASIN, RIO BLANCO COUNTY, COLORADO. Ege, John R. (Geological Survey, Denver, Colo.). Feb. 1967. 12p. Dep. mn.

Includes Drawings.

Analysis of oil assays, structure sections, and isopach maps of the Parachute Creek Member of the Green River Formation indicates that numerous locations in the western part of the Piceance Creek basin could be selected with an oil shale section at least 500 feet thick that contains not less than 20 gallons per ton of shale oil, and has at least 800 feet of overburden.

204 (TID-23184) APPLICATION OF NUCLEAR EXPLOSIVES TO CREATE UNDERGROUND GAS STORAGE RESERVOIRS. Progress Report. Atkinson, C. H.; Ward, Don C. (Bureau of Mines, Bartlesville, Okla. Bartlesville Petroleum Research Center). Jan. 1966. 18p. Dep. mn.

The use of nuclear explosives to create underground gas storage reservoirs in impermeable rock appears technically feasible. Economic feasibility depends on the need for storage where there are no depleted oil and gas reservoirs, aquifers that can be located and developed relatively inexpensively, or salt deposits suitable for solution cavities. Storage cavities created with nuclear explosives offer a potential saving over mined cavities and liquefying natural gas storage. Areas in the U. S. meeting the above criteria for economic feasibility appear to be plentiful. If required, decontamination of nuclear storage cavities appears practicable using commercially available gas processing equipment.

205 (UCRL-1224-T) THE POTENTIAL APPLICATION OF NUCLEAR EXPLOSIVES FOR THE RECOVERY OF OIL FROM SHALE. Lombard, David B. (Lawrence Radiation Lab., Univ. of California, Livermore). Dec. 1, 1964. Contract W-7405-eng-48. 21p. Dep. mn.

The possibility of using nuclear explosives to break shale for in situ retorting is discussed. Overburden removal by nuclear excavation and mining by caving of a nuclear chimney are also considered. Underground explosions in the 20 to 50 kton range can be used to thoroughly fracture large amounts of oil shale at a cost of $0.57 to $1.20 per barrel of petroleum if a recovery of 25 g/ton is assumed. Explosions of 100 kton would break shale for around $0.32 per barrel. However, shale particle size studies showed that fragment sizes in the nuclear chimney might be suitable for in situ retorting, and that the bulk permeability will be very high.

206 (UCRL-12229) EFFECTS OF UNDERGROUND NUCLEAR EXPLOSIONS ON NATURAL GAS WELL PERFORMANCE. Rodean, Howard C. (Lawrence Radiation Lab., Univ. of California, Livermore). June 23, 1965. Contract W-7405-eng-48. 17p. Dep. mn.

A completely contained, underground nuclear explosion produces a cavity filled with gas (the vaporized nuclear explosive plus the shock-vaporized rock) and lined with a layer of melted rock. Beyond this cavity, the surrounding rock is crushed and fractured out to distances of several cavity radii. The crushed and fractured rock above the cavity generally collapses, forming a chimney several cavity radii in height. These phenomena have potential applications to the natural gas industry in increasing well productivity and in forming reservoirs for gas storage. It is shown that a chimney and fractured zone (with the dimensions and properties measured in and near the Hard-hat chimney) increase the effective well radius to such an extent that the gas flow rate at early times may be increased approximately one order of magnitude. The rubble-filled chimney and adjacent fractured zone also add significant capability to a well in meeting intermittent peak load demands, and may be used as a gas storage reservoir.

207 (UCRL-13242) ECONOMICS OF UNDERGROUND GAS STORAGE IN CAVITIES CREATED BY NUCLEAR EXPLOSIONS. Final Report. (California Univ., Berkeley. Coll. of Engineering). Oct. 13, 1966. Contract W-7405-eng-48. 5p. Dep. mn.

In an appropriate geologic setting underground chimneys created by nuclear explosions offer excellent possibilities for storing gas. For devices with yields in the range of 10 to 100 kt, total storage volume varies from 0.1 to 1.4 billion ft^3/explosion. It appears that nuclear storage may be competitive with liquid (LNG) storage.

208 (UCRL-14429) EFFECTS OF NUCLEAR EXPLOSIONS ON GAS WELL HEAD AND GAS FIELD EQUIPMENT. Rabb, David D. (California Univ., Livermore. Lawrence Radiation Lab.). Sept. 23, 1965. Contract W-7405-eng-48. 6p. Dep. mn.

Two simulated well head configurations consisting of welds, valves, pipes, and casing survived nuclear explosions when installed on the surface at 950 and 1200 ft from the 1300 ft deep emplacement hole for a 10 kt explosion and a second explosion of 5 kt at a depth of 500 ft. Well head equipment can survive without damage in regions where peak surface accelerations are in the order of 5 g. These experiments did not provide information relative to the survival of existing wells under pressure in the area close to a nuclear explosion.

209 (UCRL-14877) ECONOMICS OF NUCLEAR EXPLOSIVES IN DEVELOPING UNDERGROUND GAS STORAGE. Witherspoon, Paul A. (Lawrence Radiation Lab., Univ. of California, Livermore). July 29, 1966. Contract W-7405-eng-48. 30p. Dep. mn.

In an appropriate geologic setting, nuclear explosives can create underground chimneys with a wide range in storage capacity. Under optimum conditions, the gas capacity is of the order of 10,000 MCF per kt of yield. This assumes a maximum pressure equal to hydrostatic, but higher pressures should also be possible. A nuclear chimney has the distinct advantage that one can produce gas over a very wide range of flow rates with essentially the same equipment. Flow rates of 10,000 to 500,000 MCFD have been investigated, and optimum investments costs using a 50-kt explosive range from $2.00 to $4.00 per MCF of working gas. At a given flow rate, costs are essentially inversely proportional to the yield of the explosive. Optimum depths for nuclear explosives will probably range from 2000 to 4000 ft.

210 (UCRL-50380) PROPOSED STATIONARY OR MOBILE OIL SHALE RETORTING SYSTEM. White, Elmer (California Univ., Livermore. Lawrence Radiation Lab.). Nov. 30, 1967. 39p. Dep.

An investigation of the minimum power required for retorting oil shale in situ using the thermal heat from a nuclear reactor revealed the necessity of having a 340 MW reactor. In order to map temperature profiles in a nuclear chimney, a new equation was derived which computes the ratio of the solid-to-fluid temperature. Heat exchangers and pumping power requirements were established for the model under consideration. The cost of the nuclear retorting system is negligible when prorated over the lifetime of the reactor.

211 (UCRL-Trans-10200) APPLICATION OF NUCLEAR EXPLOSIONS IN THE EXTRACTION OF OIL. Kudymov, B. Ya.; Lovlya, S. A.; Lokhova, T. F. Translated by A. M. A. Mincer for Univ. of California, Lawrence Radiation Lab., Livermore, from Tr. Sess. Uch. Sov. Nar. Ispol'z. Vzryva, 5th, Frunze, Kirg. SSR, July 1963, 5: 283-5(1965). 7p. Dep.

The possibilities of using nuclear explosions for the extraction of oil from various strata are discussed.

1. Project Bronco

Reports

212 (PNE-1400) BRONCO OIL SHALE STUDY. Project BRONCO. (Bureau of Mines, Laramie, Wyo. Petroleum Research Center). Oct. 13, 1967. 64p. Dep.

The feasibility of using deeply buried underground nuclear explosions to break oil shale deposits for in situ retorting was examined. A nuclear explosion experiment was recommended to be designed to test the concept. The nuclear concept involves firing a deeply buried, totally contained nuclear explosive to fracture the shale, which would then be retorted in place. A number of methods of retorting the broken oil shale, and associated fracture zones are described. A location in the Piceance Creek Basin in western Colorado has been investigated as a site for further studies and field investigation. It is recommended that safety and engineering field work are done to determine whether the location is suitable for a field test. Project Bronco, a proposed 50-kiloton nuclear explosion experiment is described. The detonation will fragment and fracture a deep, thick oil shale deposit which will subsequently be retorted in place. Bronco will provide information related to: the technical and economic feasibility of the basic concept, a predictive capability for the physical effects of nuclear explosions, and the distribution of radioactivity and its behavior during retorting. Although the Bronco experimental design is based on a potential site in the Piceance Creek Basin, a pre-shot investigation will determine whether the nominated site will meet the technical and safety criteria for a first nuclear explosion in oil shale. Following site confirmation, holes will be drilled for fracture studies, emplacing the explosive, and for shock wave measurements. The explosion is expected to produce a chimney 230 ft across and 520 ft high (measured up from the shot point), containing over one million tons of fragmented oil shale. Fractures may extend as far as 460 ft laterally beyond the chimney edge. Postshot drilling will reveal the size and shape of the chimney, the extent of fracturing, and the distribution of heat and radioactivity. Final design of the in situ retorting experiment will depend on results of the post-shot exploration and on laboratory research currently under way. Tentatively, mixtures of air and recycle gas will be injected via drill holes to the chimney top. Drill holes to the chimney bottom will remove off-gas, oil mist, and liquid oil. During retorting, measurements will be made of temperatures in the chimney. Samples of gas and oil will be analyzed for physical characteristics, chemical composition, and radioactive content, if any. Additional data on retorting efficiency will be obtained in post-retorting drill holes. It is planned to follow the chimney retorting with an experimental outward moving treatment in a 45° sector of the fractured region outside the nuclear chimney.

213 (UCRL-50339) A DESIGN FOR PROJECT BRONCO, AN EXPERIMENT FOR NUCLEAR FRACTURING AND IN SITU RETORTING OF OIL SHALE. Lombard, David B.; Bray, Bruce G.; Sohns, Harold W.; Sterrett, Thomas S.; Brundage, Robert S.; Carpenter, Harry C. (California Univ., Livermore. Lawrence Radiation Lab.). Oct. 1967. Contract W-7405-eng-48. 39p. Dep.

Project Bronco, a proposed 50-kiloton nuclear explosion experiment is described. The detonation will fragment and fracture a deep, thick oil shale deposit which will subsequently be retorted in place. Bronco will provide information related to: the technica and economic feasibility of the basic concept, a predictive capability for the physical effects of nuclear explosions, and the distribution of radioactivity and its behavior during retorting. Although the Bronco experimental design is based on a particular site in the Piceance Creek Basin, a preshot investigation will determine whether the nominated site will meet the technical and safety criteria for a first nuclear explosion in oil shale. Following site confirmation, holes will be drilled for fracture studies, for emplacing the explosive, and for shock wave measurements. The explosion is expected to produce a chimney 230 ft across and 520 ft high (measured up from the shot point), containing over one million tons of fragmented oil shale. Fractures may extend as far as 460 ft laterally beyond the chimney edge. Postshot drilling will reveal the size and shape of the chimney, the extent of fracturing, and the distribution of heat and radioactivity. Final design of the in situ retorting experiment will depend on results of the postshot exploration and on laboratory research currently underway. Tentatively, mixtures of air and recycle gas will be injected via drill holes to the chimney top. Drill holes to the chimney bottom will remove off-gas, oil mist, and liquid oil. During retorting, measurements will be made of temperatures in the chimney. Samples of gas and oil will be analyzed for physical characteristics, chemical composition, and radioactive content, if any. Additional data on retorting efficiency will be obtained in post-retorting drill holes. It is tentatively planned to follow the chimney retorting with an experimental outward-moving burn in a 45° sector of the fractured region outside the nuclear chimney.

2. Project Gasbuggy

Published Literature

214 PROJECT GASBUGGY: STATUS REPORT. Atkinson, Charles H.; Ward, Don C. (USBM, Bartlesville, Okla.). J. Petrol. Technol., 19: 1319-24(Oct. 1967).

Project Gasbuggy is a joint government-industry experiment to test the effectiveness of underground nuclear explosions for stimulating oil and gas production from low-permeability reservoirs. The project was approved by the Atomic Energy Commission (AEC) in 1965, and federal funds became available in Nov., 1966. The Project Gasbuggy contract was signed by the AEC, El Paso Natural Gas Co. (EPNG) and U. S. Dept. of the Interior in Jan., 1967. One month later, two preshot wells were drilled and tested at the expense of EPNG as part of industry's $1.8 million share of the $4.7 million project cost. Drilling the 28-in. hole for the 26-kiloton explosive began in June, 1967. All technical and safety programs are scheduled for a shot date of Nov. 14, 1967. Preshot core, log and test data, and hydrological data obtained in accordance with the reservoir evaluation program developed by the primary technical participants—EPNG, USBM and Lawrence Radiation Laboratory (LRL), Livermore, Calif.—revealed that the Pictured Cliffs gas reservoir met criteria for site acceptability, including considerations of safety. Preshot reservoir and production data, and programs related to safety, public information and postshot exploration are discussed.

Films

215 PROJECT GASBUGGY: The Resourceful Atom, Popular and Professional level, 14¼ minutes, color, 1968, produced by AEC's San Francisco Operations Office and El Paso Natural Gas Company. For sale by W. A. Palmer Films, Inc., 611 Howard Street, San Francisco Calif. 94105, at $51.67 per print, including shipping case, F.O.B. San Francisco. Available for loan (free) from AEC Headquarters and field libraries. Cleared for television.

Man's hope to harness the atom's explosive force for peaceful purposes moved closer to fulfillment deep beneath a plateau in northern New Mexico in December 1967. Gov't. and industry joined forces for the first time to study whether nuclear explosions can be safely used to perform massive underground engineering tasks for more efficient recovery of natural resources. "Project Gasbuggy" is the film story of that historic challenge.

Reports

216 (PNE-1001) GASBUGGY PRESHOT SUMMARY REPORT. Holzer, Fred (ed.) (California Univ., Livermore. Lawrence Radiation Lab.). Nov. 1967. 20p. (UCRL-50345). Dep.

Two holes, GB-1 and GB-2, were drilled and completed naturally approximately 190 and 300 feet, respectively, from the explosive-emplacement hole, GB-E. The Pictured Cliffs sandstone, extending from 3916 to 4202 ft below the surface, has the following average properties: bulk density, 2.47 g/cm^3; compressional velocity, 13,500 ft/sec; porosity, 10%; and water saturation, 58% (4 to 5%

water content by weight). The total gas in place is calculated to be 5.8 billion cubic feet (bcf) per 160 acres. When zones having water saturations of 60% or more are eliminated, a net volume of 4.7 bcf is obtained. While core permeabilities average 0.16 md, indicated in situ permeabilities from buildup tests are between 0.01 and 0.02 md. In GB-1, about 50% of the gas came from a single fracture between 4000 and 4020 ft deep, and most of the remainder came from bedding planes in the Fruitland zone, between 3800 and 3882 ft. In GB-2, most of the gas came from a fracture near the top of the Pictured Cliffs. In view of the complex flow pattern, values of reservoir characteristics derived from flow tests must be considered apparent only. The 26-kt nuclear explosion at the base of the Pictured Cliffs is expected to create a chimney between 330 and 400 ft high with a radius of 78 ft. Fracturing should extend radially about 400 ft. No flooding of the chimney with water is expected. The chimney gas is expected to contain about 200 μC of tritium and 2 μC of ^{85}Kr per cubic foot of gas at normal temperatures and pressures. Rapid flaring of three chimney volumes might reduce these concentrations by a factor of ten.

217 (PNE–1003) GASBUGGY PRELIMINARY POSTSHOT SUMMARY REPORT. Holzer, Fred (California Univ., Livermore. Lawrence Radiation Lab.). Jan. 1968. Contract W-7405-eng-48. 19p. (UCRL–50386). Dep.

The Project Gasbuggy nuclear explosion of nominally 26-kt yield was detonated on Sunday, December 10, 1967. Indications are that the explosive performed satisfactorily. Preliminary information is available on subsurface and surface ground motions, on the extent of the fractures, on the gas pressure in the chimney, and on the concentration of radionuclides. Subsurface ground velocities measured in instrument hole GB-D located 1470 ft from the emplacement hole range from about 1.15 to 1.6 m/sec depending on the gage location. These values are somewhat but not surprisingly higher than expected. Peak surface velocities range from 1.6 m/sec at the surface above the explosion to about 0.4 m/sec 8400 ft away. Both these data as well as preliminary values of ground motion out to a range of 60 miles are in very good agreement with preshot expectations. No damage was sustained by any of the conventional gas wells which were as close as 2600 ft to the explosion, and no structural damage has been reported from the surrounding area. Reentry drilling through the 7-in. casing on which the explosive canister was lowered established connection with the chimney at a depth of 3907 ft below the ground surface. A gas pressure of 833 psi was measured at the surface, and some xenon-133 activity was detected in samples. No other radioactive nuclide has been detected in the gas, although gas samples taken at depth have not as yet been analyzed. Density, gamma-radiation, and caliper logs indicate that a number of breaks or offsets have occurred ranging from 3805 ft down to the void at 3907 ft. These locations are in good agreement with data from fracture instrumentation in GB-1, correlate with preshot rock weaknesses, and compare favorably with predictions. Data from preliminary short term flow tests are not conclusive, and cannot be considered significant relative to either reservoir evaluation or chimney volume determination. Future work should shed light on the connection of the reentry hole with the chimney and on the nature of the chimney itself.

218 (UCID–15132) ACCEPTABILITY OF THE GASBUGGY SITE. Rawson, Donald E.; Korver, John A. (California Univ., Livermore. Lawrence Radiation Lab.). Apr. 12, 1967. Contract W-7405-eng-48. 126p. DTIE.

Test hole GB-1, the initial exploration hole at the proposed Gasbuggy Project site, is located in Rio Arriba County, New Mexico. No hydrologic data were collected in the section above the Ojo Alamo Sandstone. Two hydrologic tests were made in the Ojo Alamo Sandstone. The first test was made on February 23, 24, 1967 in the upper part of the sandstone in the depth interval 3,475 to 3,575 feet below the kelly bushing. The transmissibility of this zone is 0.4 gallons per day per foot, a very low value. The static water level is roughly 1,000 feet below land surface. The second test was made on February 26 and 27, 1967 in the lower part of the sandstone in the depth interval 3,575 to 3,654 feet below the kelly bushing. The transmissibility of this section was calculated to be 2.6 gallons per day per foot. The heat so far as is known is near that in the upper part of the sandstone. The transmissibility of the lower section is inferred to be somewhat higher than that in the upper part because of the greater number of fractures. The conductivity of the water in the sandstone is about 9,000 micromhos, or about 5,500 milligrams per liter of dissolved solids. In the Kirtland, Fruitland, Pictured Cliffs and upper part of the Lewis Formations, the section was drilled with gas as the circulating medium, after the hole was cased into the upper part of the Kirtland Shale. Water was not encountered in sufficient quality to prevent recovery of dry cuttings. Some core sections recovered in the lower part of the Pictured Cliffs Sandstone and upper part of the Lewis Shale were reported to be moist but the yield of water to the hole is inferred to be very small. No water was detected during drilling and testing of the Fruitland Sandstone. Therefore, this formation probably will not cause a water problem during the Gasbuggy experiment. The transmissibility of the Ojo Alamo Sandstone was found to be 0.412 gpd/ft in the upper 100 feet and 2.64 gpd/ft in the lower 70 feet. The separation between the bottom of the Ojo Alamo Sandstone (approximate elevation 3,654 feet) and the bottom of the Pictured Cliffs Sandstone (estimated elevation 4,150 feet) is about 500 feet. Should fracturing caused by the nuclear detonation reach the Ojo Alamo Sandstone, the low transmissibility of the sandstone would indicate that entry of water into the chimney would cause filling of the chimney at a rate estimated to be no greater than one foot a day.

219 (UCID–15132(Add.)) ACCEPTABILITY OF THE GASBUGGY SITE. Addendum. Rawson, Donald E.; Korver, John A. (California Univ., Livermore. Lawrence Radiation Lab.). Aug. 14, 1967. 7p. DTIE.

Two invalid assumptions were made in the model used for the original analysis of the Gasbuggy site. The first was that water is incompressible, and the second that water at the site is unconfined. New calculations were made with a model which takes into account both the confinement and compressibility of the water at this site. The results of the new calculations indicate little likelihood of flooding of the Gasbuggy chimney.

220 (UCRL–50334) NUCLEAR OPERATION: PROJECT GASBUGGY. Woodruff, Wayne R. (California Univ., Livermore. Lawrence Radiation Lab.). Oct. 19, 1967. Contract W-7405-eng-48. 9p. Dep.

The nuclear-operation portion of a Gasbuggy-like experiment is described. Included are the planning and design required for the selection and containment of the explosive, specifications for the arming and firing cable, preparation and construction of the test hole, and the procedures used for emplacement, arming, detonation, and post-shot radiation safety monitoring.

221 (UCRL–50425) GASBUGGY: POSTSHOT INVESTIGATIONS IN GB-ER. Korver, J. A.; Rawson, D. E. (California Univ., Livermore. Lawrence Radiation Lab.). Apr. 19, 1968. 28p. Dep.

Postshot reentry of the emplacement hole began on December 12, 1967, and terminated at a total depth of 3,916 ft on January 10, 1968. The hole below 3,000 ft was drilled with water and gel because of wet hole conditions. Two voids (from 3,856 to 3,862 ft and from 3,907 to 3,916 ft) and a number of casing breaks and offsets were encountered. Subsequent geophysical logging and short term flow tests suggest that the lower void could be considered part of the "chimney," but that it is only poorly connected with the major void volume. It is also felt that the chimney geometry is strongly influenced by horizontal fracturing, so that the chimney top is a poorly defined region of sags, or slump blocks. It must be recognized, however, that these conclusions are based on minimal data, and new information may alter them.

3. Project Ketch

Reports

222 (PNE–1200) PROJECT KETCH: A FEASIBILITY STUDY ON CREATING NATURAL GAS STORAGE WITH NUCLEAR EXPLOSIONS. (Columbia Gas System Service Corp., Columbus, Ohio. San Francisco Operations Office (AEC), Calif. California Univ., Livermore. Lawrence Radiation Lab. Bureau of Mines, Washington, D. C.). July 1967. 55p. Dep.

The feasibility of using nuclear explosives to create underground gas storage was examined to help fill a growing need for natural gas storage capacity. The nation now has less than 4½ trillion cubic ft of such storage and could use an additional 5 trillion cubic ft if available at low cost. A contained underground nuclear explosion produces void space which could be used for storage of natural gas near the consumer end of natural gas transmission lines. Storage facilities so developed offer the potential of being economically superior to mined cavities and cryogenic natural gas facilities. They may also be competitive in areas where natural storage in depleted gas fields exists but is growing scarce, or where rapid deliverability of stored gas is a factor. A site approximately 12 miles southwest of Renovo, Pennsylvania, has been selected for

illustrative purposes to evaluate this gas storage concept. The design for Project Ketch at Renovo calls for detonating a 24-kiloton nuclear explosive at a depth of 3,300 ft in a thick impermeable shale formation. The detonation would create a rubble filled chimney with a radius of 90 ft and a height of about 300 ft. Fractures are not expected to extend beyond 650 ft above the detonation point. There would be no air blast effects, and radiation effects would be safely contained underground. This void space would permit storage for about 465 million standard cubic ft of gas at 2100 psi pressure.

D. WATER AND WASTE DISPOSAL

Published Literature

223 ATOMIC TOOLS IN DEVELOPING WATER. Piper, Arthur M. (Geological Survey, Menlo Park, Calif.). 9p. (CONF-650973-1).

From National Water Well Association Conference, Houston, Tex.

Potential advantages and limitations of using nuclear explosives at suitable depths as a tool in the development and management of water are discussed. The results of a 1 kt detonation in silicate and carbonate rocks are described. Liability and legal obstacles are reviewed.

224 NUCLEAR EXCAVATION IN WATER RESOURCES DEVELOPMENT. Biswas, Asit K. (Strathclyde Univ., Glasgow). Civil Eng. (N. Y.), 61: 1375-9(Nov. 1966).

The possible uses of nuclear excavation in water resources development programs are presented. The basic concepts of nuclear cratering are discussed. The major problems of nuclear excavation, e.g., radioactivity, air blast, and seismic effects, are discussed as they relate to the use of nuclear explosives for peaceful purposes. The feasibility of using nuclear excavations for the storage of water, ground water recharge, recreational purposes, and in building a sea-level canal is discussed. It is concluded that more research and development programs will have to be undertaken before routine commercial use of nuclear excavation becomes practical. The technical problems of using nuclear explosions can be solved. The major problem is the alleviation of fear in the minds of the public concerning any type of nuclear explosion, however safe it may be. The establishment of public confidence and acceptance would be extremely difficult.

Reports

225 (PNE–3008) WATER RESOURCE APPLICATIONS, UNDERGROUND STORAGE OF NATURAL GAS, AND WASTE DISPOSAL USING UNDERGROUND NUCLEAR EXPLOSIONS. Cohen, Gerald D.; Sand, Francis M. (Mathematica, Princeton, N. J.). Aug. 31, 1967. Contract AT(04-3)-691. 82p. Dep.

Three separate papers dealing with peaceful uses of nuclear explosives are presented. The first reviews the need for augmenting natural water supplies by the end of this century, presents four ways in which nuclear explosives could aid in the recovery, storage, or treatment of water supplies, and recommends further experiments to verify the safety and feasibility of these applications. The second compares the cost of the nuclear process with conventional method costs. In terms of the combined cost of both creating the storage space and deliverability, the nuclear method shows great promise. Further research on the geologic settings and of locations for feasible application, as well as the safety consideration costs, is indicated. The third paper concluded that the use of nuclear explosives for creating underground storage for the disposal of sewage and industrial effluents is expensive and not currently warranted, but could prove to be a valuable addition to an anti-pollution program.

226 (TEI-873) POTENTIAL APPLICATIONS OF NUCLEAR EXPLOSIVES IN DEVELOPMENT AND MANAGEMENT OF WATER RESOURCES. PRELIMINARY CANVASS OF THE GROUND-WATER ENVIRONMENT. Piper, Arthur M. (Geological Survey, Washington, D. C.). 1968. 173p. Dep.

A preliminary survey of the ground water environment within the U. S. to identify areas and sites that conceivably offer hydrologic advantages in the use of nuclear explosives in the development and management of water resources is discussed. The potentials for nuclear detonation are presented by ground water provinces. These include the Pacific Border mountains, alluvial valleys and basins, Colombia Plateau, Rocky Mountains, Colorado Plateaus and Wyoming Basin, High Plains, unglaciated Central Lowland and plains, glaciated Central Lowland and plains, unglaciated Appalachia, and the Atlantic and Gulf Coastal Plain. Restrictions on practicable nuclear detonation are summarized. These restrictions derive from uncertainty as to dimensions of cavity and collapse chimney formed by a detonation at depth, side effects of detonation, e.g., ground motion, air blast, and dispersal of radioisotopes produced by the detonation, comparative economics of nuclear versus conventional methods, and legal considerations.

227 (UCRL–70762) NUCLEAR EXPLOSIVES: A POTENTIAL TOOL FOR THE DEVELOPMENT OF WATER RESOURCES. Korver, John A. (California Univ., Livermore. Lawrence Radiation Lab.). Nov. 8, 1967. Contract W-7405-eng-48. 11p. (CONF-671118-1). Dep.

From 3rd Annual American Water Resources Conference, San Francisco, Calif.

The use of nuclear explosions as a tool in the development of water resources is described. Properly sited nuclear craters can be used for ground water recharge, surface water storage, flood control, drainage, and recreation, nuclear chimneys can be used for waste disposal, and aquifier protection and diversion. The safety and economic feasibility of constructing nuclear craters and chimneys for water resources projects is discussed.

IV. OTHER APPLICATIONS

A. GENERAL

1. Project Gnome

Published Literature

228 MINERALOGICAL INVESTIGATIONS IN THE DEBRIS OF THE GNOME EVENT NEAR CARLSBAD, NEW MEXICO. Kahn, J. S.; Smith, D. K. (Univ. of California, Livermore). Contract W-7405-eng-48. Amer. Mineral., 51: 1192-9(July 1966). (UCRL-7879).

Mineralogical studies on debris formed during the underground Gnome nuclear explosion in a salt horizon of the Salado formation near Carlsbad, New Mexico have shown that significant quantities of olivine and kirschsteinite are present in the water insoluble fraction. Particles containing these minerals are generally strongly radioactive and suggest the minerals have had a role in localizing fission products. The size (10−500 μ) and spherical shape of the silicate particles suggest that they were immiscible droplets in the salt melt which preferentially dissolved the fission products before crystallizing. The subsequent crystallization excluded the actinides from within the crystallites, leaving them on the crystallite boundaries.

229 PRIMARY GROUND DISPLACEMENTS AND SEISMIC ENERGY NEAR THE GNOME EXPLOSION. Berg, Joseph W. Jr.; Trembly, Lynn D.; Laun, Philip R. (Oregon State Univ., Corvallis). Bull. Seismol. Soc. Amer., 54: 1115-26(Aug. 1964).

Attempts were made to determine the energy in the primary seismic wave at distances between 0.3 and 10 km from the GNOME nuclear explosion. To accomplish this, it was necessary to make comparisons between a theoretical description of the seismic wave and the observed data in this range of distances. Near-source measurements of seismic waves from GNOME made by the U. S. Coast and Geodetic Survey were compared to the waveforms from a theoretical source derived by Blake. It is estimated that 75% of the seismic energy in the primary waves is contained in the first half-cycle of the ground displacement as shown on the seismograms from instruments located between 0.3 and 10 km from the explosion. The geometrical attenuation of the radiation field of the displacement wave is probably closely approximated by spherical divergence at ranges near the explosion. There is some evidence that a long-period displacement field may exist near the explosion as predicted by the theoretical model. However, there are not sufficient empirical data from the GNOME explosion to make a detailed comparison between theory and observation. Measurements of ground motion near an explosion are needed that will better define the initial seismic disturbance.

B. SCIENTIFIC RESEARCH APPLICATIONS

Reports

230 (ORNL-P–2389) FEASIBILITY OF CERTAIN EXPERIMENTS USING UNDERGROUND NUCLEAR EXPLOSIONS.

Dabbs, J. W. T. (Oak Ridge National Lab., Tenn.). [1966]. Contract W-7405-eng-26. 5p. Dep. mn.

Two types of experiments using underground nuclear-explosions are discussed; experiments with nuclei oriented at very low temperatures, and direct measurements of fission lifetimes. In the first type, it was concluded that such experiments, especially fission experiments, probably should not be performed using an underground nuclear explosion as a neutron source, because of unavoidable heating associated with the rapidity of the experiment. It was found that only a small number of unusual cases are at all feasible. In the second type, a new experiment was proposed in which the passage of a recoiling compound nucleus through a crystal lattice may provide direct time-of-flight determinations of the lifetime against fission. The experiment utilizes the recently discovered "blocking" or "anti-channeling" effect in crystals. The feasibility of the experiment was discussed, with the conclusion that such neutron fission experiments are possible only with underground nuclear explosions as neutron sources.

1. Heavy Element

Published Literature

231 FISSION AND THE SYNTHESIS OF HEAVY NUCLEI BY RAPID NEUTRON CAPTURE. Bell, George I. (Los Alamos Scientific Lab., N. Mex.). Contract W-7405-eng-36. Phys. Rev., 158: 1127-41(June 20, 1967). (LA-DC-8513).

The role of fission is examined in the synthesis of heavy nuclei by multiple capture of neutrons in thermonuclear explosions. Evidence from the recent Tweed and Cyclamen experiments indicating that neutron-induced fission is a serious source of depletion in neutron capture chains which start from targets of ^{242}Pu and ^{243}Am is reviewed. An analysis of Tweed abundances is made to obtain capture-to-fission ratios for the odd-A plutonium isotopes through A = 253. The liquid-drop model of Myers and Swiatecki plus empirical shell corrections and pairing energies is then used in order to correlate and predict spontaneous fission lifetimes and fission barriers. For nuclei having $Z \leq 101$ and $N \leq 157$, the shell correction is extrapolated, assuming it to be a function of N plus a function of Z. Thus, neutron binding energies, fission barriers, and spontaneous fission lifetimes for neutron-rich heavy nuclei are obtained. Capture-to-fission ratios are estimated for many of these nuclei, and qualitative agreement is found with laboratory and Tweed results. The extrapolation is continued out to N = 159 and Z = 104. It is concluded that by using the liquid-drop model plus semiempirical shell corrections, one can obtain capture-to-fission ratios and spontaneous fission half-lives which are usefully accurate. However, for predicting properties of nuclei having $Z > 104$, $N \gtrsim 159$, one needs, in this formalism, an accurate way of predicting shell corrections or nuclear masses.

232 HEAVY ISOTOPE ABUNDANCES IN MIKE THERMONUCLEAR DEVICE. Diamond, H. (Argonne National Lab., Ill.); Fields, P. R.; Ghioroso, A.; Thompson, S. G.; Browne, C. I.; Smith, H. L.; et al. Phys. Rev., 119: 2000-4(Sept. 15, 1960).

The Nov. 1, 1952, thermonuclear explosion ("Mike") produced all of the uranium isotopes ^{239}U, ^{240}U, ... ^{255}U through multiple neutron capture by ^{238}U. The long-lived products of successive β decays from these isotopes were measured mass spectrometrically and radiometrically. The logarithms of the abundances decline smoothly with increasing mass number; the even-mass abundances slightly exceed the geometric mean of adjacent odd-mass abundances. Some nuclear properties of neutron-rich heavy nuclides, not subject to ordinary investigation, are inferred.

233 NUCLEAR DECAY PROPERTIES OF HEAVY NUCLIDES PRODUCED IN THERMONUCLEAR EXPLOSIONS: PAR AND BARBEL EVENTS. Phys. Rev., 148: 1192-8(Aug. 19, 1966). (UCRL-14500).

The nuclear decay properties of heavy nuclides ($A \leq 257$) produced in two low-yield thermonuclear explosions, the Par and Barbel events, were studied with the following results. The α-decay branching of ^{253}Cf was observed, $E_\alpha = 5.978 \pm 0.005$ MeV, $\alpha/(\alpha + \beta^-) = 0.31 \pm 0.04\%$. The α-decay branching of ^{255}Es was observed, $E_\alpha = 6.300 \pm 0.003$ MeV, $\alpha/(\alpha + \beta^-) = 8.5 \pm 0.3\%$. The spontaneous fission half life of ^{250}Cm was remeasured and was found to be $1.74 \pm 0.24 \times 10^4$ years. Upper limits for the half lives of ^{252}Cm and ^{251}Bk were set at 2 and 3 days, respectively. The existence of 80-day ^{257}Fm was confirmed; a sample of ^{257}Fm from the Par event decayed with a half life of 94 ± 10 days. Attempts to produce and detect ^{258}Fm by irradiating Par ^{257}Fm in a reactor neutron flux were unsuccessful. Upper limits for the half life of ^{258}Fm were determined.

234 RADIOISOTOPE PRODUCTION BY NUCLEAR EXPLOSION. Gerrard, Martha. Isotop. Radiat. Technol., 3: 315-16 (Summer 1966).

The distribution of ^{242}Cm, ^{241}Am, ^{239}Pu, ^{228}Th, ^{210}Po, ^{204}Tl, and ^{3}H from a nuclear explosion in a salt deposit and the means by which these nuclides might be recovered are discussed. Data indicated that the most important minerals formed by reactions of the rock with the atmosphere and with materials introduced into the shot room or by reactions among the rock components were magnetite, olivine, kirschtenite (or monticellite) with considerable iron substitution, and lead compounds. Activity was distributed in the lower third of the cavity but inhomogeneously.

235 TRANSURANIUM ELEMENTS THROUGH NUCLEAR EXPLOSIVES. Waltersoheid, Ed (Los Alamos Scientific Lab., N. Mex.). Nucl. News, 9: 16-18(July 1966).

The production of transuranium elements in underground nuclear explosions is discussed. The practicality of this idea results from the total integrated neutron flux estimated to be 1.2×10^{25} N/cm^2 from the detonation.

Reports

236 (ANL-7134) PROCESSING OF ROCK DEBRIS FOR TRANSPLUTONIUM ELEMENTS PRODUCED BY UNDERGROUND NUCLEAR DETONATIONS. Horwitz, E. P.; Bloomquist, C. A. A.; Harvey, H. W.; Hoh, J. C. (Argonne National Lab., Ill.). Feb. 1966. Contract W-31-109-eng-38. 24p. Dep. mn.

Chemical processes used for recovery of transplutonium elements and Pu from rock samples from underground nuclear explosions are described. Recovery efficiencies using the described procedures are estimated to be better than 90% on a kilogram scale.

237 (DP-1055) RECOVERY OF ACTINIDES PRODUCED BY A NUCLEAR DETONATION IN VOLCANIC TUFF OR DESERT ALLUVIUM. Karraker, David G.; Perkins, William C. (Du Pont de Nemours (E. I.) and Co., Aiken, S. C. Savannah River Lab.). Dec. 1966. Contract AT(07-2)-01. 18p. Dep. mn.

A chemical process was developed to recover transplutonium elements from the debris of a thermonuclear device detonated underground at the Nevada Test Site of the AEC.

238 (LA-DC-8103) PRODUCTION OF HEAVY ELEMENTS IN A RECENT LOS ALAMOS THERMONUCLEAR TEST. Hoffman, Darleane C. (Los Alamos Scientific Lab., Univ. of California, N. Mex.). [1966]. Contract W-7405-eng-36. 8p. (CONF-660817-3). Dep. mn.

From International Symposium on Why and How Should We Investigate Nuclides Far Off the Stability Line, Lysekil, Sweden.

A low-yield thermonuclear device, designed to give a high-neutron-flux region for the purpose of producing heavy elements by multiple-neutron capture, was recently tested underground in Nevada. This device, Cyclamen, containing ^{238}U and ^{243}Am target material, was the most successful heavy element producer to date, giving an order of magnitude more ^{257}Fm than any previous Nevada test. The mass abundance data indicated that still heavier nuclides should have been produced in amounts sufficient to permit detection, but no evidence for them has yet been found. Although it was not expected that the even mass chains would have survived, predicted α half lives for ^{259}Fm and ^{259}Md are $\approx$20 years and $\approx$80 days, and it might be expected that their spontaneous fission half lives would be in the range of about a month. However, if it is assumed that these nuclides were produced with an abundance of $\frac{1}{30}$th that of the mass 257 chain, present data permit the following half life limits to be set: for ^{259}Fm, $t_{1/2}(SF) \leq 5.5$ hr or ≥ 7.5 years and $t_{1/2}(\alpha) \geq 30$ years, and for ^{259}Md, $t_{1/2}(\alpha) \geq 30$ years. The implications of the failure to find evidence for mass 259 are discussed.

239 (UCRL-14494) COACH PROCESSING: A STUDY OF PROCESSES FOR CONCENTRATING ACTINIDES FORMED IN A NUCLEAR DETONATION IN A SALT MEDIUM. Elson, R.; Boardman, C.; Cooperstein, R.; (and others) (California Univ., Livermore. Lawrence Radiation Lab.). May 25, 1965. Contract W-7405-eng-48. 275p. Dep.

The Coach processing effort was designed to determine the technical feasibility of separating about 1 g of transcurium actinides from an estimated 30,000 to 50,000 tons of impure salt, resulting from a nuclear detonation in the Solado formation near

Carlsbad, New Mexico. The association of actinides with specific compounds was investigated in an attempt to devise specific separation procedures based on the chemistry of these compounds. Since >88% of the material originally present was soluble in water, an efficient and economical means of removing the bulk of material was an aqueous leach, leaving the actinides in the water-insoluble residue. The actinides, along with most of the water-insoluble residue, could then be solubilized by treatment with acid. The actinides were then concentrated with dioctylpyrophosphoric acid, since this acid is relatively insensitive to interfering ions and has a high solvent power for the actinides. A program was undertaken to test various unit operations on a small engineering scale. Debris from the Gnome event, detonated in the same location as that planned for Coach, served as material for most of the studies reported. Topics covered include: aqueous processes; high-temperature, molten-salt processes; bench-scale engineering tests; preliminary cost estimation; association of actinides in ore; use of the transplutonics as neutron sources; and determination of Pu, Am, and Cm.

240 (UCRL-50441) EVALUATION OF THE PROMPT SAMPLE SYSTEMS USED FOR THE ANACOSTIA AND KENNEBEC EXPERIMENTS. Brady, Jack D. (California Univ., Livermore. Lawrence Radiation Lab.). Mar. 15, 1968. 14p. Dep.

As a part of the Plowshare scientific program, two low yield thermonuclear devices (Anacostia and Kennebec) were fired underground at the Nevada Test Site in November 1962 and June 1963. These experiments were designed to produce very heavy elements by multiple neutron capture in a ^{238}U target. Rapid recovery of the resultant products was attempted using the force of the explosion to blow debris up a 10-in. dia, liquid filled pipe to the ground surface and collect the debris in retention tanks. Small samples recovered from the retention tanks immediately after the explosions were poorer in transuranium elements than were the core samples obtained later from postshot drilling. Radiochemical analyses of additional samples recovered from the collection tanks and piping of each prompt sampling system show that the Anacostia system collected between 10 and 40 kg of solids with a specific Pu content (dis/min-g of dry rock) equivalent to good puddle glass samples. The Kennebec system collected 360 kg of chemically fractionated rock with a specific Pu content nearly equal to puddle glass samples.

2. Neutron Physics

Published Literature

241 FISSION CROSS SECTIONS OF ^{241}Am AND ^{242m}Am. Seeger, P. A.; Hemmendinger, A.; Diven, B. C. (Los Alamos Scientific Lab., N. Mex.). Contract W-7405-eng-36). Nucl. Phys., A96: 605-16(1967). (LA-DC-7624).

The acquisition and analysis of neutron cross section data from an experiment using an underground nuclear detonation are discussed with specific reference to fission cross sections measured in the Petrel event in June 1965. Results are presented for ^{242}Am and ^{242m}Am over the energy range 20 eV to 1 MeV, measured simultaneously in a single experiment covering the entire energy range, with very low background. Considerable sub-threshold fission was observed for ^{241}Am. The fission cross section of the doubly odd nuclide ^{242m}Am is about twice that of ^{239}Pu over most of the neutron energy range, but only about 20% greater at 1 MeV.

242 RESONANCE ANALYSIS OF THE ^{233}U FISSION CROSS SECTION. Bergen, D. W.; Silbert, M. G. (Los Alamos Scientific Lab., N. Mex.). Phys. Rev., 166: 1178-89(Feb. 20, 1968). (LA-DC-8946).

The neutron-induced fission and capture sections of ^{233}U were measured by time of flight with a nuclear detonation as the neutron source. Cross-section data are presented from 20 to 10^6 eV for fission and from 30 to 63 eV for the capture-to-fission ratio α. Data in the resonance region (20 to 63 eV) were fitted both by a single-level function consisting of a sum of Briet–Wigner levels and by the Reich–More multilevel function based on R-matrix theory. The resulting resonance parameters are listed and discussed. A study of cross sections derived from two and three hypothetical resonances under various conditions of interference is presented to determine the validity of the resonance parameters derived from the multilevel fit.

Films

243 PERSIMMON: A NUCLEAR PHYSICS EXPERIMENT, professional level, 16 minutes, produced by AEC's Los Alamos Scientific Laboratory.

This film explains that for several years the Los Alamos Scientific Laboratory has been using the intense burst of neutrons produced by the underground detonation of a nuclear explosive to perform a variety of nuclear physics experiments. A relatively small nuclear detonation will produce the same quantity of neutrons, in a fraction of a second, that would take a laboratory accelerator hundreds of years to produce. Thus, experiments requiring a very high neutron flux, or a hopelessly long-running time on an accelerator, become feasible with a nuclear explosion as the neutron source. The motion picture presents and discusses the various experiments that comprise the Persimmon event and climaxes with the actual detonation of the nuclear explosive and the consequential collapse and cratering of the ground above it.

Reports

244 (CONF-660303) CONFERENCE ON NEUTRON CROSS SECTION TECHNOLOGY, MARCH 22-24, 1966, WASHINGTON, D. C. Hemmig, P. B. (ed.) (Atomic Energy Commission, Washington, D. C.). 1098p. Dep. mn.

This report issued in two books, but cataloged as a unit.

Separate abstracts were prepared for 46 of the 89 papers included. For remaining papers, see items under CONF-660303 in the report-number index.

245 (IDO-17174) THE FISSION CROSS SECTION OF ^{241}Pu FROM 20–200 ev AS DETERMINED FROM A NUCLEAR EXPLOSION. Simpson, O. D.; Fluharty, R. G.; Moore, M. S.; Marshall, N. H. (Phillips Petroleum Co., Idaho Falls, Idaho. Atomic Energy Div.); Diven, B. C.; Hemmendinger, A. (Los Alamos Scientific Lab., Univ. of California, N. Mex.). Apr. 1966. Contract AT(10-1)-205. 25p. Dep. mn.

A nuclear explosion was used as a neutron source for a measurement of the neutron-induced fission cross section of ^{241}Pu. Over the region from 20 to 200 eV, the region of thermal neutron energies of the source, the flux was high enough to permit the determination of fission cross sections with a minimal error. A comparison of these data with previous measurements of the fission cross section of ^{241}Pu shows that a significant improvement was made, both in resolution and in statistical accuracy. The data below 60 eV were analyzed with the use of a multilevel formula.

246 (LA-3478(Pt.2)) TIME-OF-FLIGHT NEUTRON CROSS SECTION MEASUREMENTS USING NUCLEAR EXPLOSIONS. PART II. Seeger, P. A.; Bergen, D. W. (Los Alamos Scientific Lab., N. Mex.). Dec. 20, 1966. Contract W-7405-eng-36. 39p. Dep. mn.

The procedures used for converting analog (film) records of data obtained from the interaction of nuclear-device-produced neutrons with target nuclei to cross sections as a function of neutron energy are described. A discussion of the errors is also presented. The conversion procedures include digitizing the records; converting all data to signal, S(t), vs time; deriving a background to be subtracted from all signals; deriving a flux based on the known cross section of a foil isotope; and obtaining the cross section by converting signal to reaction rate and dividing by the flux and foil density.

247 (LA-3586) FISSION CROSS SECTIONS FROM PETREL. (Los Alamos Scientific Lab., N. Mex.). Sept. 19, 1966. Contract W-7405-eng-36. 231p. Dep. mn.

Fission data obtained in the Petrel event of June 11, 1965, are presented graphically and in tables, including calculated standard deviations. The isotopes studied were ^{233}U, ^{235}U, ^{239}Pu, ^{240}Pu, ^{241}Pu, ^{241}Am, and ^{242}Am; the neutron energy range covered for most isotopes was 20 eV to 1 MeV.

248 (LA-3676) THE ^{233}U FISSION AND CAPTURE CROSS SECTIONS AND THEIR ANALYSIS AT LOW ENERGIES. Bergen, Delmar W. (Los Alamos Scientific Lab., N. Mex.). Dec. 1966. Contract W-7405-eng-36. 76p. Dep.

Thesis. Submitted to Univ. of New Mexico [Albuquerque].

The ^{233}U fission and capture cross sections were measured using a nuclear-device neutron source and time-of-flight techniques. Cross section data are presented from 20 to 10^6 eV for fission and from 20 to 63 eV for fission + capture. The resonance region (20 eV to 63 eV) was fitted with both a single-level function consisting of a sum of Breit–Wigner levels and the Reich and Moore multilevel function based on R-matrix theory. The resulting resonance parameters are listed and discussed. In order to establish the validity of the resonance parameters derived from the multilevel fit, a study is presented of the cross section de-

rived from two and three hypothetical resonances under various conditions and of the cross sections obtained from randomly generated resonances.

249 (LA-DC-7304) NEUTRON EXPERIMENTS WITH UNDERGROUND NUCLEAR EXPLOSIONS. Diven, B. C. (Los Alamos Scientific Lab., Univ. of California, N. Mex.). [1965]. Contract W-7405-eng-36. 18p. (CONF-650706-22). Dep. mn.

From International Conference on the Study of Nuclear Structure with Neutrons, Antwerp.

Techniques were developed that use nuclear explosions as pulsed neutron sources for time-of-flight experiments. Measurements of capture and fission cross sections were made. Some preliminary results are presented.

250 (LA-DC-7799) USE OF NUCLEAR EXPLOSIONS AS PULSED NEUTRON SOURCES. Diven, Benjamin C. (Los Alamos Scientific Lab., Univ. of California, N. Mex.). [nd]. Contract W-7405-eng-36. 4p. (CONF-660303-19).

From American Physical Society. Conference of Neutron Cross Section Technology, Washington, D. C.

The use of nuclear explosions as neutron sources for cross-section measurements is briefly discussed. The status and future development of the method are considered, as well as plans for future measurements.

251 (LA-DC-7864) NEUTRON CROSS-SECTION MEASUREMENTS OF RADIOACTIVE NUCLIDES USING NEUTRONS FROM AN UNDERGROUND NUCLEAR EXPLOSION. Brown, W. K.; Diven, B. C.; Seeger, P. A. (Los Alamos Scientific Lab., Univ. of California, N. Mex.). [1966]. Contract W-7405-eng-36. 18p. (CONF-660817-1). Dep. mn.

From International Symposium on Why and How Should We Investigate Nuclides Far Off the Stability Line, Lysekil, Sweden.

The method developed at the Los Alamos Scientific Laboratory of using time-of-flight techniques in combination with a neutron burst from the underground detonation of a nuclear explosive has opened new possibilities in neutron cross-section measurement. The enormously high neutron flux generated in such a burst can be used to give correspondingly large reaction rates in targets. An obvious exploitation of this circumstance lies in the measurement of the cross sections of radioactive nuclides. Such measurements are often impossible using conventional neutron sources due to the high radioactive background, the rapid disappearance of the target, or both. With large reaction rates, the radioactive background becomes relatively small, and the amount of sample does not change significantly in the several milliseconds during the measurement. Having demonstrated the efficacy of the method in general on the Petrel event in June 1965 at the Nevada Test Site, efforts are being directed specifically to measurements of the cross sections of radioactive isotopes. In the autumn of 1966 it is planned to measure the capture cross section of ^{147}Pm (2.7 y), a fission product from which, through neutron capture, the reactor poison ^{148}Pm is synthesized. Plans for future measurements include the capture cross section of ^{148}Pm (41 d), ^{233}Pa (27.4 d), and possibly the fission cross section of ^{235m}U (26.2 m) which would require fast chemistry under field conditions. Measurements on nuclides increasingly further from the stability line are planned. These measurements will provide basic nuclear structure information not otherwise presently obtainable. Measurement of these cross sections will strengthen the knowledge of the systematics among radioactive nuclides and lower the uncertainties in the extrapolation necessary for the analysis of r-process nucleosynthesis.

3. Seismology

Published Literature

252 CALCULATION OF FIRST-ZONE P WAVE AMPLITUDES FOR SALMON EVENT AND FOR DECOUPLED SOURCES. Springer, Donald L. (Univ. of California, Livermore). J. Geophys. Res., 71: 3459-67(July 15, 1966).

Theoretical calculations of the first half-cycle amplitudes of the P wave at 250 to 1000 km are made from source functions representing several types of nuclear explosions in salt. Specifically, they are Gnome scaled to 5 kt; Salmon; theoretical 25 kt detonated in a cavity built to fully decouple a 5-kt explosion; and theoretical 5 kt also detonated in a 5-kt cavity. The calculations consist of a series of convolutions of the source functions plus the attenuation operators plus the instrument response. Amplitude factors are calculated using Zvolinskii's near-front approximation for various assumed crustal models. Experimental amplitudes from Salmon fall below the amplitude curve for the scaled Gnome source. They are consistent with amplitudes for the Salmon source; therefore, head-wave propagation along the M discontinuity may occur in the eastern United States. This is not conclusive, however, since body-wave calculations might give amplitudes of equal consistency. Amplitudes calculated for the fully decoupled 5-kt source show a decoupling of 200. Those from the overdriven cavity source indicate that a partial decoupling of 80 can be gained by overdriving a cavity by a factor of 5.

253 CRUSTAL SEISMIC MEASUREMENTS IN SOUTHERN MISSISSIPPI. Warren, David H.; Healy, J. H.; Jackson, Wayne H. (Geological Survey, Denver). J. Geophys. Res., 71: 3437-58 (July 15, 1966).

A seismic refraction survey was made in Mississippi along a line trending north from Ansley to Oxford. About 200 seismograms were recorded from 22 chemical explosions at 5 shot points spaced at intervals of about 50 km between Ansley and Raleigh. The Salmon nuclear event, fired in the Tatum salt dome, was also recorded at several locations. A measured average velocity of 3.0 km/sec, to approximate all of the shallow sedimentary rocks, was used in depth calculations. The first strong refraction arrival represents a layer of 5.0 km/sec at a depth ranging from 3.1 to 3.7 km, just under the unconformable boundary between the Upper and Lower Cretaceous sedimentary rocks. The crustal structure is complex below the Lower Cretaceous sedimentary rocks. A curved line could be fitted to the first arrivals between 15 and 150 km on each travel-time plot, increasing in apparent velocity from 4.9 to 6.9 km/sec. All first arrivals between the 5.0-km/sec lower sedimentary rocks and the higher-velocity lower crust are included in one layer, giving an average velocity of 5.9 km/sec for "basement." The basement structure shows a low point corresponding to the trough of the Mississippi salt basin between the Tatum dome and Raleigh and a broad high feature cresting south of McNeill. First arrivals determine an intermediate layer in which the velocity is 6.9 km/sec, typical of basalt, and which rises from a depth of 19 km at McNeill to 13 km near Raleigh. Strong events are apparently reflected from the M discontinuity at critical distances and beyond, and it is necessary to supplement meager first arrivals with the reflections to arrive at a delineation of the upper mantle. The average velocity in the upper mantle is 8.4 ± 0.3 km/sec, the average crustal thickness is 35 km, and the M discontinuity dips 3° toward the south from Raleigh to Ansley. The complicated crustal structure may be due to the intermingling of two major geotectonic trends, the Appalachian and the Ouachita. Low to zero values of regional free-air gravity anomaly indicate that the region is near isostatic equilibrium. For the crustal model to be in isostatic equilibrium, the density must increase in the upper mantle below southern Mississippi. A hypothesis is made that increasing density in the mantle may be the mechanism of formation of the Gulf Coast geosyncline.

254 DEEP REFLECTIONS FROM A NUCLEAR EXPLOSION IN A SALT DOME. Perret, William R. (Sandia Lab., Albuquerque, N. Mex.). J. Geophys. Res., 72: 6327-33(Dec. 15, 1967).

Data from four special gages in a boring, offset 166 meters from the Salmon nuclear explosion 828 meters deep in the Tatum salt dome, include five groups of reflection signals from below the source. The gages, accelerometers of high sensitivity to vertical motion, were at depths between 673 and 1190 meters. These data, interpreted by means of U. S. Geological Survey's crustal study data for the Tatum dome vicinity, yield depths to Louann-basement contact of 8.23 km, an unidentified interface near 13 km, the Conrad discontinuity at 17.1 km, an interface at 33 km, and the Mohorovicic discontinuity at 34.6 km. The last two reflections imply a transition zone at the crustal mantle contact. Uniqueness of these data lies in identical vertical paths from source to reflecting surface to detectors, a point source of high energy, and a vertical array of detectors of high vertical resolution.

255 DETECTION, ANALYSIS, AND INTERPRETATION OF TELESEISMIC SIGNALS. I. COMPRESSIONAL PHASES FROM THE SALMON EVENT. Archambeau, C. B.; Finn, E. A.; Lambert, D. G. (Teledyne, Inc., Alexandria, Va.). J. Geophys. Res., 71: 3483-3501(July 15, 1966).

The travel times and amplitude spectra of first- and later-arrival P phases from the Salmon event are computed on the basis of polarization filter outputs. The interpretation of the P wave radiation field is made in terms of crust and mantle structure using the first- and later-arrival P phases and their amplitude spectra. The observed seismic field corresponds with that expected from a symmetric, purely compressive source. The es-

sential features of the observed travel times and amplitudes are explained in terms of regional mantle structures. These structures provide first-order fits to the observed data and are characterized by low-velocity zones which terminate with rapid and continuous increases in velocity near depths of 130 km. The velocity structures also show a strong velocity gradient near 330 km. The regional models differ most strongly in the relative extent and magnitude of the velocity decrease in the low-velocity zone.

256 EPICENTER DETERMINATION FOR THE SALMON EVENT. Herrin, Eugene; Taggart, James (Southern Methodist Univ., Dallas). J. Geophys. Res., 71: 3503-6(July 15, 1966).

With data obtained from earthquakes and explosions before the Salmon event, it was possible to compute regional travel-time corrections and station corrections which reduced the location error for Salmon by a factor of 10 if times from all (91) stations were used, and by a factor of 2 if times from only distant stations were used. When all stations were used, the error was less than 2 km, and the 0.90 confidence ellipse had an area of about 100 km^2. The computation when times from 23 distant stations ($\Delta > 20°$) were used gave an error of less than 6 km, a 0.90 confidence ellipse of about 900 km^2, and a 0.75 confidence ellipse of 500 km^2. The latter ellipse covered the true location.

257 NUCLEAR DECOUPLING, FULL AND PARTIAL. Patterson, Dan W. (Univ. of California, Livermore). J. Geophys. Res., 71: 3427-36(July 15, 1966).

An underground explosion in a cavity is said to be fully decoupled if the cavity is large enough for the explosion to produce only elastic motion in the walls; in a smaller cavity where the wall motion is elastoplastic, the explosion is said to be partially decoupled. The pressure histories on the walls of cavities in salt of suitable size for decoupling sources are calculated and used in computing the motions of the walls, including the effect of elastoplastic behavior of salt. From the motion of the cavity walls, seismic displacement potentials are calculated and compared with the measured close-in displacement potentials for the Salmon event (5 kt) and the Gnome event (3.1 kt) scaled to 5 kt, both tamped (tightly coupled) nuclear detonations in salt. The close-in decoupling ratios for salt thus obtained are 350 for Gnome data and 200 for Salmon data. The reduced displacement potential based on the Gnome measurement at 298 m and scaled to the 5-kt size of Salmon is found to be 40% above the measured Salmon value of 300 m; the Gnome measurement may have been in the inelastic region or it may have been influenced by stronger horizontal propagation due to bedding planes. Reduced displacement potentials are also calculated for shots of 100 tons, 0.5 kt, and 1 kt, all in a cavity volume for 100-ton decoupling. They are 0.47, 5.0, and 45 m^3, respectively, as compared with 80 m^3 for a 100-ton fully tamped shot.

258 P-WAVE COUPLING OF UNDERGROUND NUCLEAR EXPLOSIONS. Springer, Donald L. (Univ. of California, Livermore). Bull. Seismol. Soc. Amer., 56: 861-76(Aug. 1966).

An analysis is made of the transmission of seismic energy through various detonation media as influencing interpretation of seismic signals from underground nuclear explosions. P-wave amplitude data for underground nuclear explosions are correlated with detonation energy. Amplitudes are reproducible to 25% when source media and propagation path differences are minimized. These data verify theoretical scaling relations and establish relative coupling for various shot media. An empirical correlation of these amplitude data with dry porosity of the detonation medium indicated that a medium with 60% dry porosity may couple explosive energy one-fourth or one-fifth as efficiently as does alluvium. The relation of teleseismic magnitude to explosive yield for various types of low coupling showed that dry porous media give a significant reduction of seismic signals generated by underground nuclear explosions. Inspection of teleseismic magnitude-yield curves, with an assumption of the magnitude thresholds for detection and/or identification of earthquakes and underground explosions, will automatically give yield thresholds for underground nuclear device testing. For instance, a detection threshold of magnitude 4 gives 10 kt as the min yield detectable for alluvium coupling. The min yield detectable for dry ashfall or wet diatomite type coupling is estimated to be 50 kt. The full decoupling curve (for salt) is shown for comparison.

259 REVIEW OF THE SALMON EXPERIMENT: A NUCLEAR EXPLOSION IN SALT. Rawson, D. E.; Taylor, R. W.; Springer, D. L. (Univ. of California, Livermore). Contract W-7405-eng-48. Naturwissenschaften, 54: 525-31(Oct. 1967). (UCRL-70260).

The Salmon experiment was conducted to investigate the generation and propagation of seismic waves from an explosion in a salt dome. The effect on the surrounding salt including inelastic response near the explosion such as vaporization, melting, crushing, cracking, and plastic flow and the more distant seismic or elastic responses are summarized. The inside of the cavity was studied by television and photographic cameras. A 0.35 kT nuclear device was detonated in the cavity to study decoupling.

260 SALMON SEISMIC EXPERIMENT. Werth, Glenn; Randolph, Philip (Univ. of California, Livermore). J. Geophys. Res., 71: 3405-13(July 15, 1966).

The Salmon nuclear detonation of October 22, 1964, had a nuclear yield of 5.3 ± 0.5 kt. The teleseismic magnitude was 4.35. P waves observed out to 2500 km show asymmetries in the propagation, with high amplitudes ($m\mu$/sec), faster apparent velocities, and higher signal frequencies to the north and northeast than to the west. At teleseismic distances, many of the signals were very weak and could be identified with Salmon only because the time of detonation and expected arrival time were known. If a cavity were built of a size to fully decouple 5 kt at the Salmon site, theoretical calculations which include the nuclear shock predict a decoupling factor of about 170 or a magnitude of 2.1. If such a cavity were used for partially decoupling a 25-kt shot, the magnitude is predicted to be 3.1. Drilling back into the Salmon shot region revealed a standing shot cavity of 20,000 m^3, corresponding to a sphere of radius 17 meters.

261 TRAVEL TIMES AND AMPLITUDES FROM THE SALMON EXPLOSION. Jordan, James N.; Mickey, Wendell V.; Helterbran, Wayne; Clark, Don M. J. Geophys. Res., 71: 3469-82(July 15, 1966).

Salmon, an underground nuclear explosion in the Tatum salt dome in southern Mississippi, was seismically recorded throughout North America and at some overseas stations. Data are presented from 143 seismograph stations recording signals from the Salmon event. Travel times at smaller distances generally confirm the high upper mantle velocities indicated by Gnome as recorded in the eastern United States. Travel times for the area east of the Rocky Mountain front may generally be represented by the equation $t = \Delta/8.3 + 8$ seconds (Δ in kilometers); however, additional detail is shown indicating apparent velocities of up to 8.7 km/sec. In the 10 to 20° distance range multiple arrivals are apparent, and beginning near 16° late initial arrivals are observed which correspond to Jeffreys–Bullen travel time. Amplitudes were generally higher than expected for regional and for teleseismic distances but lower in the 13 to 22° range in the western United States. A revision to procedures for determining magnitudes is shown to be necessary.

Reports

262 (UCRL-50182) REAPPRAISAL OF THE APPLICATION OF STATIC EQUILIBRIUM THEORY TO DECOUPLING. Knox, Joseph B.; Hearst, Joseph R. (California Univ., Livermore. Lawrence Radiation Lab.). Jan. 19, 1967. Contract W-7405-eng-48. 22p. Dep.

The static theory of seismic coupling of contained nuclear explosions developed by Haskell was applied to 44 nuclear explosions, and macro-scale values of the Coulomb–Mohr constant were estimated. These values for granite and salt were then used to estimate the signal-reducing effectiveness of fully decoupled cavities in these media. Granite was found to be three times more effective. The results of the calculations indicate that for cavities overdriven by a factor of 2 or more, Hardhat granite is about 60% more effective than salt in diminishing the reduced displacement potential.

263 (UCRL-50232) THEORETICAL AMPLITUDES AND TRAVEL TIMES OF EXPLOSION-GENERATED SEISMIC P WAVES. Roberts, John (California Univ., Livermore. Lawrence Radiation Lab.). Apr. 5, 1967. Contract W-7405-eng-48. 10p. Dep.

Amplitudes and travel times have been calculated for the first half-cycle of seismic P waves generated by nuclear explosions at distances varying from 140 to 2900 km. The head-wave-body-wave model constructed yields travel times within ±3.9 sec of the mean experimental values over the indicated range of distances and also

provides an interpretation of the large-small-large nature of the amplitudes.

264 (VUF-3014) EARTH VIBRATIONS FROM A NUCLEAR EXPLOSION IN A SALT DOME. Project DRIBBLE, SALMON Event. Final Report. Mickey, W. V.; Lowrie, L. M.; Shugart, T. R. (Coast and Geodetic Survey, Rockville, Md.). Mar. 17, 1967. 166p. Dep. mn.

Recorded earth particle motions in terms of displacements, velocities, and accelerations were near predictions in the distance range of 1.5 to 603 km for the 5 kt SALMON nuclear detonation in a Mississippi salt dome. These motions included measurements from nearby cities and industrial facilities. Scaled earth motions from HE detonations of 500 to 4000 lb in the unconsolidated shallow sediments were consistently higher than the motions recorded from SALMON. Asymmetric seismic energy propagation was observed with more efficient propagation to the north and south. Apparent velocities of the first arrivals were: 1.458 to 6 km from ground zero, east 2.82 km/sec, south 2.67 km/sec; 6 to 100 km, 4.77 km/sec; and 100 to 630 km southwest, 8.5 km/sec. The maximum motions were propagated at near 1.9 km/sec. The horizontal resultant vector for first motion was anomalous for three stations with deviations from a radial path of 36.2 to 66°. Equivalent earthquake magnitude from calculated seismic energies was near 5.1 with a source-seismic energy ratio of 0.47%.

265 (VUF-3015) SEISMIC VELOCITY DETERMINATION AND DISTANCE MEASUREMENTS IN A SALT DOME. PROJECT DRIBBLE, SALMON EVENT. McLamore, V. R. (Teledyne Industries, Inc., Pasadena, Calif. Earth Science Div.). Apr. 1965. 72p. Dep. mn.

The downhole hardware and recording system designed to record high frequency energy including both compression and shear wave arrivals with unprecedented resolution is described. The compressional (4516 m/sec) and shear wave (2520 m/sec) velocities determined between the air filled 17½-in. dia uncased hole (Station 1-A) and mud filled 12¼-in. dia uncased hole separated by approximately 22.5 m in the depth interval 701 m to 762 m are internally consistent and accurate to ±1%. This conclusion is believed valid in spite of trouble with the depth measuring equipment and resultant requirement for elaborate data reduction in which shot depths were adjusted based on the constraints that the compressional velocity was constant in the region investigated and that the holes were near vertical. It was demonstrated that distance measurements between the drill holes can be made to an accuracy of ±2% or one foot, whichever is greater for ranges out to at least 140 m. However, if these data are to be used to emplace downhole hardware with significant vertical separations after the measurement, a downhole reference point is recommended to overcome the problems inherent in measuring from the surface with accuracy of a few parts in 10,000. The up-hole surveys in instrument holes E-4 (318.6 m, n 57°41′ E of GZ), E-11 (615.2 m, S 75°38′ W of GZ) and WP-4 (340.4 m, S 19°15′ W of GZ) gave compressional wave velocities of 4570 m/sec, 4570 m/sec, and 4544 m/sec, respectively. The minimum accuracy of the uphole surveys is ±5% with probable accuracy being in the order of ±3%. The average of the four velocity determinations made is 4550 m/sec. The spatial variation in these observed velocities is 54 m/sec, or 1.2%.

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